National Park Service
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Northeast Region
Inventory & Monitoring Program
Northeast Temperate Network
Woodstock, Vermont

Revolutionary Changes to an American Landscape: Invasive Plant Species at the Minute Man National Historical Park

Technical Report NPS/NER/NRTR--2005/009

ON THE COVER
Purple Loosestrife: *Lythrum salicaria*
Photograph by: Brad Agius

Revolutionary Changes to an American Landscape: Invasive Plant Species at the Minute Man National Historical Park

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Introduction

Systematic data collection and long-term monitoring of natural communities is essential for understanding and managing environmental threats. Without baseline data, current and future generations lack the ability to track changes to the environment (Pauly 1995). In the absence of long-term data, it cannot be determined if observed changes in the environment are catastrophic, unusual, or rare, nor to assess causation from human perturbations, disturbance events, or invasive species (Sebens et al. 1997).

The Minute Man National Historical Park (park) conducted an invasive plant survey during the summer of 2003 to generate baseline data to manage and assess the spatial impact of invasive plants. The primary goals of this study were to 1) determine which invasive plant species inhabit the park; 2) determine the percent cover and density of the dominant invasive plant species; and 3) map where dominant invasive plant species occur within the park.

The NPS and the park are mandated to protect native species while at the same time controlling invasive species. NPS *Management Policy 2001* prohibits parks from permitting non-native species to displace native species when it can be prevented (section 4.4.4, *Management of Exotic Species*, in NPS 2001). Additional NPS policy states that "exotic plant species. . .will be managed - up to and including eradication - if. . .the exotic species interferes with natural processes and the perpetuation of natural features, native species or native habitats; or. ..disrupts the accurate presentation of a cultural landscape." The National Leadership Council's 1999 *Action Plan for Preserving Natural Resources* also addressed threats posed by non-native species and recommended that the NPS "act aggressively with a well-targeted effort to control non-native species" (NPS 1999). The park's Resource Management Plan contains a goal "to eliminate or reduce non-native species that pose a threat to native species or cultural areas. . ." (NPS 1993). In addition, Executive Order # 13112 requires that federal agencies must “prevent the introduction of invasive species and provide for their control and to minimize the economic, ecological, and human health impacts the invasive cause” (Federal Registry 64[25]: 6183-6186).

Global environmental change is detrimentally altering natural ecosystem function upon which all life depends (Mooney and Cleland 2001). The rapid increase in human population is the principal cause of recent global environmental change (McKee et al. 2003). Among the major threats posed by global environmental change are global warming, habitat alteration, resource depletion, pollution, and invasive species (Carlton 2000, Palumbi 2002). These global environment threats are not isolated in their impact on the natural world and can interact in a deleterious synergism (Agius 2003). For example, global warming has dramatically increased the number of invasive species in native forests in the United States (Simberloff 2002). The loss of biodiversity around the globe is one of the most serious environment problems of our times, to only be exacerbated by the increase in the number of invasive species (Chapin et al. 2003).

While many exotic plant species introduced to new locations are not problematic or invasive in their home range, they often become severe problems in locations outside their natural range. These species have been described as alien, exotic, non-native, and nonindigenous, and those that are particularly aggressive are termed invasive. However, not all invasive plant species are exotic (e.g., in New England poison ivy is a native plant, but exhibits invasive growth), while some non-indigenous species are not invasive. In this report, the term "invasive" plant describes xenobiota (xenbiota are species that are both invasive and exotic [Carlton 2001]), while the term "exotic" is used to describe plants not native to New England (without indicating if growth is invasive or not).

Invasive species inflict immense ecological and economic damage on a global scale. A meta-analysis conducted by Pimentel et al. (2001) indicated more than 120,000 exotic species have invaded the United States (U.S.), United Kingdom, Australia, South Africa, India, and Brazil, causing $314 billion annually in U.S. dollars. Invasive species are represented in almost every taxonomic group; among the more notably destructive species are zebra mussels (*Dreissena polymorpha*), green crabs (*Carcinus maenus*), hydrilla (*Hydrilla verticillata*), feral cats (*Felis catus*), Indian mongoose (*Herpestes auropunctatus*), brown tree snakes (*Boiga irregularis*), wooly adelgid (*Adelges piceae*), cholera (*Vibrio cholerae*), gypsy moths (*Lymantria dispar*), and kudzu (*Pueraria lobata*).

The origin, cause, and vectors of invasive plant species invading new habitats are not always known. Many invasive plant species arrive accidentally by human transport (e.g., seeds in soils), while others are directly transplanted and cultivated as ornamental plants for landscaping and gardens before they escape into surrounding areas. Once established, invasives endure natural growth and range expansion, often including dispersion by wind, water, and animals (Sakai et al. 2001). Birds in particular can carry seeds great distances, causing additional spreading of exotic species. Problems arise when invasive species occupy disproportionately large areas (high percent cover and/or density) in new locations, compared to their native counterparts. Many native species (plants and animals) are directly and indirectly displaced by invasive species. Not all exotic species successfully invade novel habitats after they are introduced. Some successful invasions require repeated introduction before the population is established, with the large amounts of genetic material and variation for populations to reproduce and grow out of control (Sakai et al. 2001).

There are several reasons why some exotic plant species become invasive. Many exotic plant species possess "weedy" attributes, including 1) fast growth; 2) disturbance tolerance (i.e., phenotypic plasticity); 3) high reproductive rates and output; 4) quick maturity; 5) early, late, and / or long reproductive periods; and 6) chemical defenses (Sakai et al. 2001). In addition to their aggressive growth, most invasive plants lack herbivores in their new habitats, which might otherwise keep populations in check (Keane and Crawley 2002).

Invasive species thrive in new habitats by escaping native controls formed in their original home range (Stokes 2001) and exploiting the native species and communities that cannot adapt quickly enough to deter their proliferation. Evolution is the process in

which species develop through natural selection, traditionally thought to occur over long periods of time. Species have evolved to co-exist in natural communities, but the rapid transport of species around the world has disrupted natural evolutionary processes. Mounting evidence indicates that invasive species evolve rapidly due to additive genetic variance, epistatus, hybridization, genetic tradeoffs, specific genotypes, and genomic rearrangements (Lee 2002). Before the advent of rapid transport by humans, natural geographic (e.g., oceans and mountains) and climatic barriers prevented species from attaining pangenic distributions. Currently, international commerce transports thousands of species around the globe everyday (Carlton 2001), thus homogenizing the world's biota.

In some ecosystems, increased native biodiversity makes a natural community more resistant to species invasions (Stachowicz et al. 1999), while others ecosystems exhibit the opposite effect (Levine 2000, Lonsdale 1999). The discrepancy in ecosystems that support high numbers of invasive species with high native biodiversity is largely explained by co-varying extrinsic factors, such as propagule supply (Levine 2000, Lonsdale 1999) and niche opportunity (escape from predation, resource availability, and community maturity [Shea and Chesson 2002]). Once invasive species establish in an area, communities become subject to invasional meltdown, where initial invasions pave the way for the introduction of additional invasive species (Simberloff and Van Holle 1999). In addition, the loss of rare, native, species in communities may lead to invasive species becoming successful established (Lyons and Schwartz 2001).

Once viable populations of invasive plants become established in novel habitats, they inflict a suite of ecological damage to native species including loss of habitat; loss of biodiversity; decreased nutrition for herbivores; competitive dominance, overgrowth, struggling, and shading; resource depletion; and alteration of biomass, energy cycling, productivity, and nutrient cycling (Dukes and Mooney 1999). Invasive plant species can affect hydrologic function and balance, making water scarce for native species (Enright 2000). The loss of biodiversity around the globe is one of the most serious environment problems of our times and is exacerbated by the increase in the number of invasive species (Chapin et al. 2003).

Four imperiled species may directly benefit from the habitat protected at the Minute Man National Historical Park in Massachusetts (State). Britton's violet (*Viola brittoniana*), documented on land adjacent to the park, is a State-threatened flower growing in river meadows and in wooded floodplains which are habitats under siege at the park by invasive plant species (e.g., glossy buckthorn and purple loosestrife). The spotted turtle (*Clemmys guttata*) and mystic valley amphipod (*Crangonyx aberrans*) are two species of special concern in the State of Massachusetts. Their aquatic habitats are becoming increasingly rare and jeopardized by invasive plant species in the park. Additionally, the elderberry long-horned beetle (*Desmocerus palliatus*) is another species of special concern occurring within the park boundaries in areas increasingly invaded by non-native plants.

Six additional species of endangered, threatened, and special concern to the State may occur in the park (Table 1). Although, not documented in the park, they inhabit nearby areas, and there is suitable habitat for these species in the park. These species are protected under the State of Massachusetts Endangered Species Act (M.G.L.c.131A), its regulations (310 CMR 10.00), and the Wetlands Protection Act (M.G.L.c.131.s.40). The detailed maps of the primary invasive plant species in this report may provide important resources for the protection of native species and the control of invasive plant species within the park.

Table 1. Endanger, threatened, and species of special concern likely to occur in the Minute Man National Historical Park*

Species Common Name (Latin)	MA State Status
American Bittern (*Botaurus lentiginosus*)	Endangered
Least Bittern (*Ixobrychus exilis*)	Endangered
Blanding's Turtle (*Emydoidea blandingii*)	Threatened
King Rail (*Rallus elegans*)	Threatened
Blue-Spotted Salamander (*Ambystoma laterale*)	Special Concern
Common Moorhen (*Gallinula chloropus*)	Special Concern

* note: these species have not been document in the park

Materials and Methods

Systematic surveys were conducted to quantify the abundance and distribution of terrestrial and aquatic-emergent, invasive plant species, as well as the dominant native plant species at the Minute Man National Historical Park (park). No submerged aquatic vegetation was surveyed in this study. The dominant native vegetation was recorded to determine if sufficient native plant material existed to recolonize sites naturally, following eradication of invasive species in a given area. The dominant native vegetation was categorized as trees, grasses, shrubs, and flowers.

The congressional boundary for the park encompasses 391.6 hectare (ha), including areas of private land (see Appendices B-H for locations of private lands). Private lands are defined for this report as properties not owned by the park or leased properties with uncooperative tenants; except as noted below, in either case the properties were not surveyed. The area not surveyed within the park's congressional boundary was 11.5 ha, bringing the surveyed area to 380.1 ha. All percentages calculated for the report are based on the area surveyed, not the congressional area. However, private lands that were surveyed with permission of the private landowner (i.e., Old Manse - Trustees of Reservation and Mass Port) were included in the park survey.

Initial assessment of the problematic exotic plant species during the first week of the project indicated 14 species as particularly invasive within the park (Table 2). These 14 invasive plant species (primary species) were mapped within the park, including their density and percent cover. In addition, 55 exotic plant species (secondary species) surveyed were quantified in terms of density and percent cover: however, due to time constraints, survey data for secondary species were not digitized (Table 3).

Table 2. List of the 14 primary invasive plant species mapped by creating polygons, quantifying the percent cover and density within each polygon.

Common name	Latin name	Common name	Latin name
Asian Bittersweet	*Celastrus orbiculatus*	Japanese Knotweed	*Polygonum cuspidatum*
Black Swallowwort	*Vincetoxicum nigrum*	Multiflora Rose	*Rosa multiflora*
Bush Honeysuckle	*Lonicera* spp.	Norway Maple	*Acer platanoides*
Common Buckthorn	*Rhamnus cathartica*	Phragmites	*Phragmites australis*
Common Tansy	*Tanacetum vulgare*	Purple Loosestrife	*Lythrum salicaria*
Garlic Mustard	*Allaria petiolata*	Spotted Knap weed	*Centaurea biebersteinii*
Glossy Buckthorn	*Rhamnus frangula*	Tree of Heaven	*Ailanthus altissima*

Table 3. List of 55 secondary exotic plant species surveyed. The percent cover and density of each secondary exotic plant species was quantified per grid instead of by polygon.

Common name	Latin name	Common name	Latin name
Autumn olive	*Elaegnus umbellata*	Mugwort	*Artemisia vulgaris*
Black locust	*Robinia pseudoacacia*	Mullien	*Verbascum thapsus*
Bouncing bet	*Saponaria officinalis*	Norway spruce	*Picea abies*
Broadleaf plantain	*Plantago major*	Oxeye daisy	*Chrysanthemum leucanthemum*
Buckthorn plantain	*Plantago lanceolata*	Pachysandra	*Pachysandra* sp.
Bull thistle	*Cirsium vulgare*	Pepperweeds *	*Lepidium* spp.
Catalpa	*Catalpa bignonioides*	Periwinkle	*Vinca minor*
Celandine	*Chelidonium majus*	Privet	*Ligustrum* spp.
Chicory	*Cichorium intybus*	Queen anne's lace	*Daucus carota*
Common barberry	*Berberis vulgaris*	Ragweed	*Ambrosia artemisiifolia*
Crab apples	*Malus* spp.	Red clover	*Trifolium pratense*
Creeping euonymus	*Euonymus fortunei*	Reed canary grass	*Phalaris arundinacea*
Curly dock	*Rumex crispus*	St. Johnswort	*Hypericum perforatum*
Dame's rocket	*Hesperis matronalis*	Toad flax	*Liniria vulgaris*
Day-lily	*Hemerocallis fulva*	Vetch *	*Vicia* spp.
English Ivy	*Hedera helix*	White clover	*Trifolia repens*
Field sorrel	*Rumex acetosella*	White popular	*Populus alba*
Forcynthia	*Forsythia viridissima*	Wild garlic	*Allium vineale*
Goutweed	*Aegopodium podagragia*	Wild grapes *	*Vitis* spp.
Ground ivy	*Glechoma hederacea*	Winged euonymus	*Euonymus alata*
Healall	*Prunella vulgaris*	Woods strawberry	*Fragaria vesca*
Horse chestnut	*Aesculus hippocastanum*	Woody nightshade	*Solanum dulcamara*
Japanese barberry	*Berberis thunbergii*	Yarrow	*Achillea millefolia*
Lambs quarter	*Chenopodium album*	Yellow hawk weed	*Hieracium pratense*
Leafy spurge	*Euphorbia esula*	Yellow hop clover	Trifolium aureum
Lesser stitchwort	*Stellaria graminea*	Yellow Iris	*Iris pseudocorus*
Lilac	*Syringa vulgaris*	Yucca	*Yucca filamentosa*
Lilly of the valley	*Convallaria majalis*		

* denotes cryptogenic species (may be either native or exotic)

The systematic field survey was conducted from June 23 through September 26, 2003 to cover the 392-hectare (967-acre) park. The park contains three units: North Bridge, Wayside and Battle Road (see Appendix A for park layout). Because of its small size, the Wayside Unit was completed first. The rest of the park was completed in a west to east direction, from the North Bridge to Battle Road Units (Concord to Lexington, MA, respectively).

The survey was conducted with a Garmin V GPS hand held unit plugged into a CSI MBX-3S differential receiver backpack. The Universal Transverse Mercator coordinate system (UTM), Zone 19, was used throughout the study for all GPS and GIS uses. To aid navigation and mapping, 0.5 meter (m), 1:5,000 scale, color digital aerial orthophotos (orthophotos) were used in combination with the GPS unit. The 0.5m color orthophotos where obtained from the MassGIS website (http://www.state.ma.us/mgis/) then reprojected into the UTM system.

To conduct the survey in a systematic fashion, grids at two scales were created using GIS software (ESRI ArcView 3.2) and were overlaid on the park, including 50m x 50m and 100m x 100m grids. Grids were saved in 'shapefile' format. The 100m x 100m (i.e., 1 hectare or 2.47 acres) grid was used to survey the North Bridge and Battle Road Units of the park, while the 50m x50m grid was used to survey the Wayside Unit. Each of the 390 100m x 100m and 12 50m x 50m grid cells were assigned a unique ID number that was used for referencing grid cell locations. Regardless of the grid size, the survey was conducted in the same fashion.

During the survey, there were instances when a portion of the park was not covered by the grid, but those sections were systematically surveyed as well, to cover the park in its entirety. Prior to field surveys, color maps were printed that included the grid layer with individual grid attribute ID numbers, 0.5m color orthophotos, park boundary, scale bar and north arrow. Maps typically included a block of 4 grids (at either the 50m or 100m scale) per 8.5-inch x 11-inch page~~s~~, although other grid dimensions were used when necessary.

The grid shapefile was also uploaded into the GPS unit to aid in navigation. In the field, a piece of tracing paper was placed over the 2 x 2 grid map, and the corners of the grids marked for aligning the tracing paper with the grid map. The surveyor's name, date, park, internal park location (e.g., North Bridge, Wayside, Battle Road), and grid numbers were recorded on the tracing paper. Surveys sometimes were conducted in the rain. In either rainy or wet conditions, "Write in the Rain" sheets were used in place of the tracing paper and 2 x 2 grid maps.

Each grid was surveyed by bushwhacking the perimeter and then making transects (e.g., numerous transverse passes) within the grid until completely covered, with all targeted species quantified and mapped. Pinpointing locations in the field was done by referencing features on the ground (e.g., trails, roads, water bodies, white pine trees, structures, fields, etc.) that were visible on the 0.5m color orthophotos; grid lines on the paper map; and the GPS tracks line, current position of GPS cursor, and grid lines on the GPS display screen.

Using these references enabled the survey to be conducted with an accuracy of 1m or the margin of error produced by the GPS unit.

In the field, the 14 primary species were sketched onto the tracing paper using species-specific symbols in the exact location that they occurred in the field. In certain instances, there could be greater than 100 percent cover in a given location. Vertical stratification and overlapping of invasive species was prevalent and the vertical overlapping of invasive species was denoted by overlapping symbols on the tracing paper.

All the invasive species (primary and secondary) and dominant native species were recorded after completely bushwhacking each grid cell. The density and percent cover of each of the secondary exotic species and the four dominant native vegetation classes (i.e., trees, shrubs, grasses and flowers) were recorded per grid cell, if present. The 14 primary invasive species were documented using discrete polygons in each grid cell which could be larger or smaller than a hectare, with multiple polygons per grid. Polygons were mapped on tracing paper (hand-drawn) as contiguous and discrete patches for each of the 14 primary species as they actually occurred in the field. The percent cover and density of each primary species was quantified for each polygon.

Hand-drawn polygons created on tracing paper in the field were transferred into digital format using 'heads-up' digitizing capabilities of ArcView 3.2 (ESRI 1999). A separate shapefile was created for each of the primary invasive plant species with an attribute table containing the percent cover and density for each polygon. Species that occurred at low frequencies had smaller mean polygon sizes than common species. Patch sizes and polygon occurrences were somewhat subjective, being dependent upon methods used to survey and digitize the final polygons. For instance, because this study was conducted grid by grid, there was a tendency to break up large polygons across grid borders, so caution should be used when interpreting the number of polygons (Figure 1) and mean polygon size (Figure 2). Digitizing polygons without grid border breaks would decrease the total number of invasive polygons, thereby increasing the mean polygon size for some of the invasive species.

Once digitizing and data entry was completed, spatial analysis was conducted in ArcView 3.2. and Excel (Microsoft 2002) to generate the abundance and coverages of each of the 14 primary species. Creating separate shapefiles for each primary species enabled the percent cover or density to be displayed for each species but would not allow the calculation of the total overlapping area of all 14 primary species. To determine the area cover by overlapping polygon of all invasive plant species shapefiles in ArcView, raster data (as a bitmap) was exported from ArcView to SCION Image (version 4.0.2) for calculations.

Maps (Appendices A-T) for this report were exported from ArcView as .JPG files to present the relevant invasive species data. The resolution of the final maps (in JPEG format, Appendices B-T) does not reflect all of the data viewable in the ArcView layout. In addition, more data is contained in the attribute table of the ArcView files that is not shown in the JPG files. If finer resolution maps or additional data is needed, copies are

available through the Natural Resource Manager at Minute Man National Historical Park or the Database Manager at the Northeast Temperate Network.

Results

The infestation of exotic plant species at the park was extensive. There were areas of the park in which six or more of the primary invasive plant species occupied a single $1m^2$ vertical column (e.g., occupying the canopy, lower trees, shrubs, and ground cover layers (Appendices B-G). This survey identified 3,544 discrete polygons from the 14 primary invasive plant species (Figure 1) on 380.1 ha surveyed. There was a large variation in the mean polygon size among the primary species (Figure 2). The additive area covered by all the 14 primary invasive plant species if distributions did not overlap is 361.9 ha or 95.2% of the surveyed area. However, there was vertical stratification within habitats (canopy, lower trees, shrubs, and ground cover). In other words, invasive species overlap and are invading in a three dimensional fashion. The park is 63.9% covered by the fourteen primary invasive species (Appendices B-G, for total aerial coverage) when viewing the species as they actually overlap in the park. The 63.9% of the park covered by the overlapping 14 primary invasive species is calculated on the surveyed area. However the survey area included approximately 50.6 ha of structures and managed areas (roads, paths, buildings, foundations, barns, lawns, etc.) and 30.8 ha of agricultural leased lands, all of which are "developed areas".

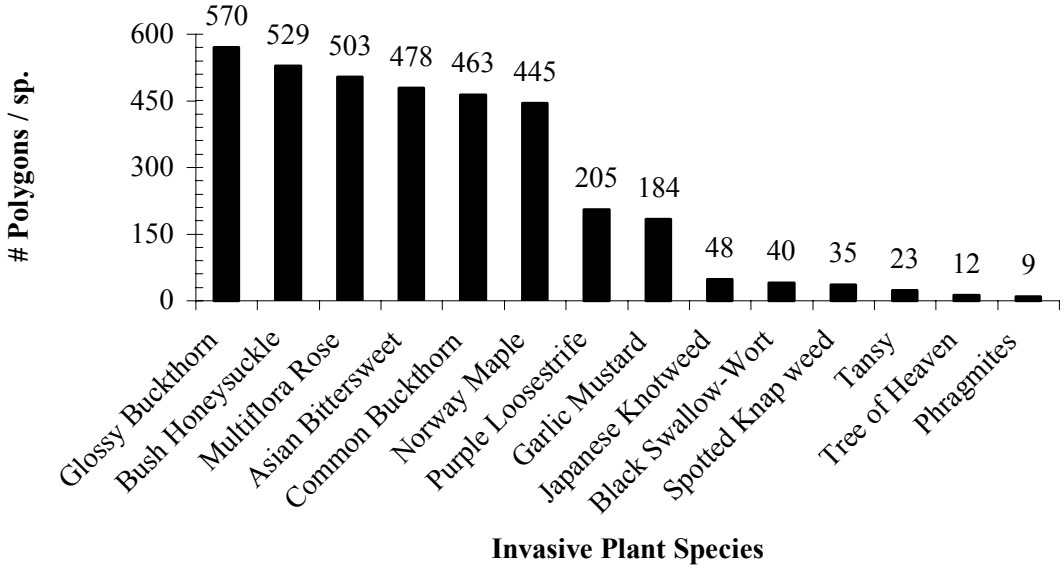

Figure 1. The number of polygons digitized for each of the 14 primary invasive plant species.

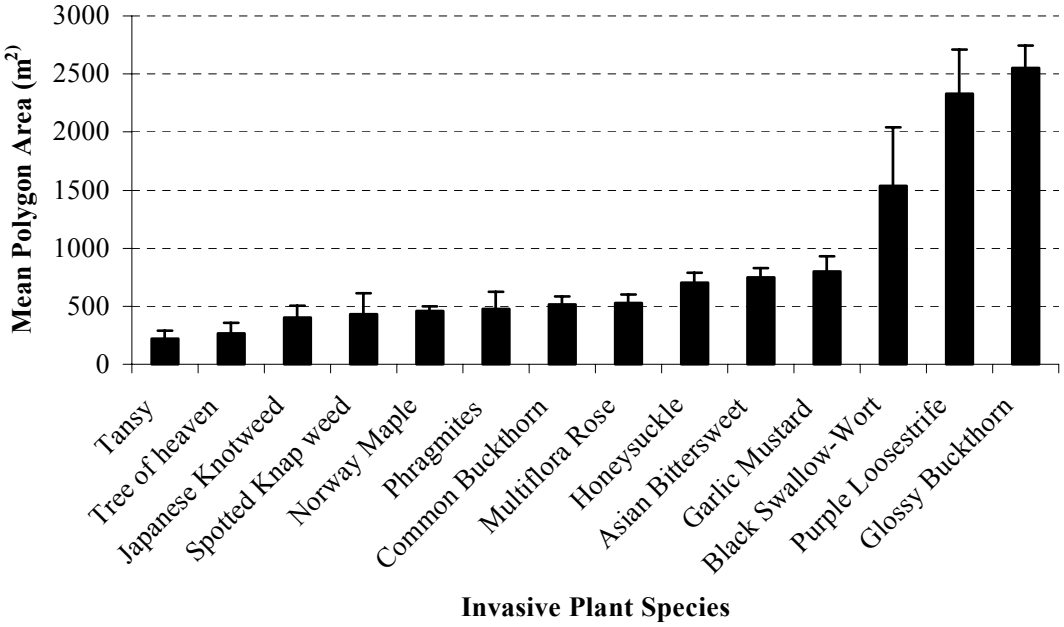

Figure 2. The mean area (m^2) per polygon for each species. Variance is presented as ± SE.

In addition, there are 10.1 ha of open water areas (Concord River, Folly Pond, etc.[Please note that open water areas that were not surveyed likely would have supported another suite of invasive plant species, such as water chestnut, *Trapa natans*]). Subtracting the developed and open water areas from those surveyed indicates that 84.2% of available natural habitat (terrestrial and emergent aquatic) is inhabited by the 14 primary invasive species.

Glossy buckthorn was documented as the most problematic invasive plant species in the park (Appendix L). At 144.7 ha of the total area covered, glossy buckthorn dominated 50.1% of the undeveloped habitat in the park, where it has invaded all areas and habitats. On a logarithmic scale (Figure 3), the area occupied by glossy buckthorn is in the same order of magnitude as area for the entire park. The park's second largest infestation (47.8 ha) is caused by purple loosestrife (Appendix Q). The combined acreage of glossy buckthorn and purple loosestrife (192.5 ha) totals more than the 12 other primary species combined (169.5 ha). For the six smallest infestations, the combined areas of tree of heaven, phragmites, tansy, spotted knapweed, Japanese knotweed, and black swallowwort equate to only 2.9% of the park surveyed (Figure 3). Appendices at the end of this report show the abundance and distribution of all of the 14 primary invasive species mapped during this survey (Appendices B-T).

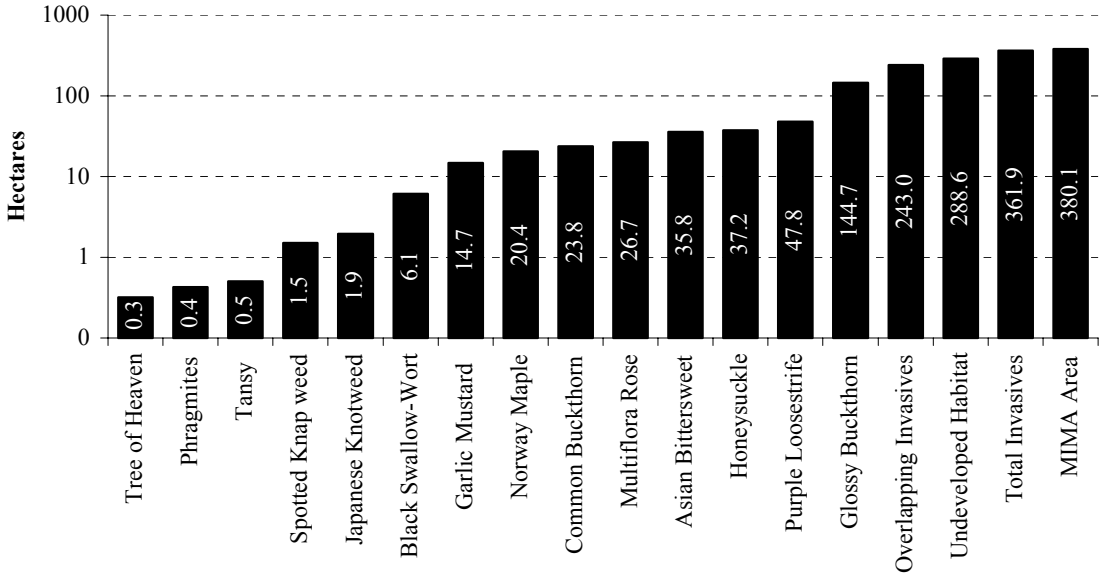

Figure 3. The area (ha) for each primary invasive species, their totals, and park area.

The 14 primary invasive plant species leave only 15.8% of the undeveloped habitats unoccupied for other plant species. That is not to say that native species do not occur within the mapped invasive areas. The natives plants also occupy three-dimensional habitats (in discrete vertical layers), and there can be greater than 100% cover in a single area that supports various species within vertically stratified habitats. Unfortunately, the 84.2% area of the primary invasive plants underestimates the total area inhabited by exotic/invasive plant species. There were an additional 55 secondary exotic plant species that were systematically recorded in this survey (Table 3). The 15.8% of the undeveloped habitats not covered by the primary invasives quickly dwindles when factoring in the dominant secondary exotic plant species and the secondary exotic plant species list did not include all of the exotic plant species found in the park.

Furthermore, recently mowed fallow fields and lawns posed a problem in identifying species, presenting another source for underestimating the full extent of coverage by invasive and exotic plants. It should be noted that lawns and fields are comprised mostly of non-native grasses, and covered in numerous exotic small flowering plants (e.g., sand spurrey [*Spergularia rubra*], silvery cinquefoil [*Potentilla argentea*], common chickweed [*Stellaria media*], etc.). Frequent mowing alters the morphology of these plants, making them difficult to identify until they flower. Exotic plants and grass species in the landscaped and mowed lawns of the park were not systematically quantified during the survey.

Discussion

Minute Man NHP was severely infested with invasive, exotic plant species during the time of this survey (2003). A small percentage of the parks undeveloped habitat remains devoid of invasive and exotic plant species. This survey identified the major problematic species and created a permanent baseline record of the abundance and distribution of the 14 primary invasive plant species for the summer 2003.

Glossy Buckthorn was the most common and widely distributed primary invasive plant in the park. Glossy buckthorn is a tall woody shrub (reaching 6m in height) and tolerant of a broad range of light and hydrologic conditions in the park. Its dominance in the park's vegetation may be due to its unusually long period of fruit production with fruits ripening in July and persisting on branches through November (The Nature Conservancy 1984a and personal observation). Buckthorn seeds are dispersed naturally by birds, mice and deer, and may be dispersed over long distances by migratory birds (The Nature Conservancy 1984a). Furthermore, glossy buckthorn seeds float in water and may raft into new areas during high water events (The Nature Conservancy 1984a).

Physically altered habitats create ideal conditions for some invasive species, such as Asian bittersweet (*Celastrus orbiculatus*), a climbing and strangling vine. Asian bittersweet thrives in disturbed soils where its seeds are able to germinate, but the seeds only have a successful dormancy of one to two years (Ellsworth 2003). "The growth characteristics of Asian bittersweet enable it to climb trees, which become over weighted and topple during heavy winds, thereby creating conditions (e.g., light gaps) suitable for the germination of additional Asian bittersweet plants. Birds disperse seeds of Asian bittersweet, as well as humans for landscaping projects (The Nature Conservancy 1984b). Asian bittersweet's advantageous growth is documented the fourth most abundant primary invasive plant in the park (12.4% of the undeveloped habitat).

Undoubtedly, the historic conditions of the park have facilitated the proliferation of invasive plant species. The area has been extensive farmed for hundreds of years. Hundreds of structures have been removed since the formation of park in 1959. Around many of the structures were gardens and landscaping containing exotic plant species. It may be a mute point since no causation can be assessed without historic data on the species and specific land use prior to this study.

However, the negative impact that invasive plants inflict on native species has been and continues to be researched. Across large areas of the Northeastern U.S., European purple loosestrife (*Lythrum salicaria*) is becoming a dominant and destructive invasive species in wetland habitats. The park is no exception, with 16.6% of the undeveloped habitat occupied by purple loosestrife. This noxious perennial weed produces roughly two million seeds plant $^{-1}$ year $^{-1}$ (Weatherbee et al. 1996) – a testament to its large reproductive output and aggressive ability to infest of wetland habitats. Purple loosestrife has been shown to reduce the biomass of the native cattail (*Typha latifolia*), leading to local extirpation of cattails (Weihe and Neely 1997) and other plant species.

Empirical evidence increasing indicates invasive plant species negatively affect native plant species. For example, black swallowwort (*Vincetoxicum nigrum*) is an invasive milkweed species that can out compete and displace native milkweed. Negative impacts extend to native animal species as well. Casagrande and Dacey (2001) showed that monarch larvae, which obligately feed on milkweed plants, die when eggs were laid on black swallowwort instead of the native milkweed species. Thus, there is a two-fold negative impact of black swallowwort on monarchs; it out competes the preferred native milkweed plants and causes mortality of larvae if eggs are laid on the ever increasing population of black swallowwort plants. Similarly, the invasive garlic mustard (*Alliaria petiolata*) causes the mortality of the native cabbage butterfly larvae, if the eggs are oviposited on the plant (Renwick et al. 2001).

It is clear that significant negative impacts are generated by invasive plants on native species. Immediate measures need to be undertaken to control the invasions underway and thwart new species from infesting the park.

Management Recommendations

Although glossy buckthorn is the most pervasive invasive plant in the park, management efforts should not focus on this species first. Instead, it would be prudent to focus efforts on keeping the 15.8% of the park that is devoid of primary invasive plants clear of any new invasive or exotic plant species and increasing the size of those invasive free areas (Simberloff 2003), instead of tackling the severely infested areas first (see Appendices B-G for the areas that are devoid of the 14 primary invasive plant species). In addition, initial efforts should focus on eradicating the following six invasive plant species: 1) tree of heaven; 2) tansy; 3) black swallowwort; 4)spotted knapweed; 5) Japanese knotweed; and 6) *Phragmites*, based on their relatively lower number of polygon occurrences (Figure 1), small mean polygon size (Figure 2), and overall acreage in the park (Figure 3). Targeting these six species could provide successful eradication of problematic species before populations have expanded and invaded additional areas.

Tree of heaven, black swallowwort, spotted knapweed, Japanese knotweed, and *Phragmites* have been identified as extremely aggressive plants and detrimental to native communities in other locations in Massachusetts (New England Wildflower Society 1998). Common tansy (*Tanacetum vulgare*) has not been listed in state and environmental group (New England Wildflower Society 1998, Weatherbee et al.1996) publications, but its dense growth in several areas of the park is troubling, and the reason for it being included on the priority species list. Although it is imperative to have supporting data to manage exotic plants, situations occur where data are lacking for speedy management.

Black swallowwort eradication is recommended for the Battle Road Unit of the park first, followed by action in the North Bridge Unit (Appendix I). While this species has a low number of occurrences (40 discrete polygons), the mean polygon size is 1,537m^2 ± 502.6 SE. The high variance in polygon size is due to large patches of heavy infestation in the North Bridge Unit, while there are only a few small patches in the Battle Road Unit. Eradicating species when populations are small (both in size and number) is a better use of time, money, and effort than trying to control species that are well established (e.g., glossy buckthorn), since small patches can quickly grow and act as a seed source for new populations (Simberloff 2003). Controlling species with low numbers of polygons, small mean polygon sizes, and small overall area in the park also requires less intrusive eradication techniques, including release of smaller amounts of herbicides into the environment and minimizing disturbance to habitats and native species.

This study documented and quantified the abundance and distribution of the invasive and exotic plant species. The management ideas are suggestions based on the data collected, the known threats of these invasive plant species in other locations (Casagrande and Dacey 2001; Pimentel et al. 2001; Renwick et al. 2001; Weihe and Neely 1997), and the literature on invasive plants (D'Antonia and Kark 2002; Mooney and Cleland 2001; Simberloff 2003). Based on the spatial distribution of the invasive plant species at the park, management can also use the estimates of native vegetation cover to determine if

native plants can re-establish themselves in eradication areas or if replanting of native species is appropriate. Future projects should analyze the secondary exotic plant species, prioritize the species according to their threats to the park (spatial distribution, growth, and reproductive output), and conduct additional surveys of species which pose additional ecological threats to native species. Invasive plant species need to be addressed at scales that exceed park boundaries, because adjacent areas may act as seed banks for continuous invasions into the park. Since reinvasions may occur, the park may never rid itself of invasive plants if efforts are not made to collaborate with adjacent landowners to manage their areas too. Regardless of long-term success, management of all the invasive species is necessary (Simberloff 2003).

Recent evidence indicates that eradication of invasive species is more advantageous than continuous biological, chemical and mechanical control (Simberloff 2001). However, the size of the park contains disproportional large infestations of invasive species that may require most of the undeveloped park to be cleared and restored. Little native species biomass would be left after removing all of the invasive plant species, which would functionally alter the benefits native species provide to the natural community. Large scale removals of invasive plants often introduce enormous secondary impacts to the native species and open the door for future, and continuous invasions (reviewed in Zavaleta et al. 2001). Nevertheless, swift action most be taken to manage invasive species, while at the same time protecting native species.

A principal mechanism (pathway) for invasive plant species to enter the park is through adjacent lands. Illegal dumping was prevalent along much of the park's borders, with much of the dumping including yard and garden waste. Some of the waste contained many exotic and invasive plant species currently affecting the park. Education and outreach to adjacent landowners and the community about the threats caused by invasive plants would be a valuable effort for the park to undertake in helping to limit future invasive plant issues. Not only does the park need to collaborate with adjacent and local property owners, the park also needs to establish a clearly defined boundary, visible to those outside the park, to limit encroachment and the dumping of contaminated garden waste. In many areas, no boundary markers were visible which may be a primary factor leading to intrusion of adjacent landowners onto park effectively contributing to a loss of acreage of NPS property. Without visible boundary markers, it is left to private citizens to know the location of the park boundary. In addition, the park should survey its boundary accurately and create appropriate GIS boundary layers to aid future survey work.

In conclusion, the park will serve the public and native species, especially the rare and threatened species, well with swift control of invasive and exotic plant species. Not only does the large infestation of invasive plant species within the park pose a threat of continual spread and increased density and percent cover, it also serves as a seed source of invasive plant species that may invade areas outside of the park property. The park and its neighbors will mutually benefit from the control of its invasive and exotic plant species, and as serve a model for environmental stewardship in the 21st century.

Additional Suggestions for the Park to Control Invasive Plant Species

1) Encourage and support academic research projects to investigate impacts to native species inflicted by invasive / exotic plant species on park property.
2) Promote and support volunteer invasive plant removal projects within and outside the park.
3) Establish an education program and displays about the threats posed by invasive species, and offer ways that individuals can contribute to eradication and restoration of native species. For instance, what species have been lost and which have invaded since the historic events of April 19, 1775?
4) Use only native species for all restoration and landscaping projects.
5) Focus on early detection and hand removal of new individuals and populations of invasive species, rather than chemical applications and biological controls.
6) Immediately remove any invasive species from the gardens and landscaping, regardless of their aesthetic value (e.g. privet, Japanese barberry, winged euonymus, tansy, etc.).
7) Ensure leased agricultural fields are cleared to the perimeter of the field every year. Otherwise, invasive plant species quickly establish themselves in dense growth formation along the edges of the fields.
8) Conduct a systematic survey to map submerged invasive aquatic plants.
9) Ensure the facilities management knows the threats of the exotic and invasive plant species and the identification of these plants. Facilities management is the park's first line of defense in many areas. They should be trained appropriately to remove invasive and exotic plant species when they encounter them. For example, effort should be made to clear out underneath trees instead of just around them.
10) Re-survey to monitor invasive species that may colonize new areas and to assess effectiveness of controls, eradication and restoration.
11) Analyze the secondary exotic plant species to establish which species pose the greatest threat at the park. Then, complete subsequent, detailed surveys that include those species that pose the largest risk as was done with the 14 primary invasive plant species in this report.
12) Monitor for leafy spurge in the field west of the public parking lot leading to the Minute Man Visitor Center in Lexington, MA. Identify and eradicate any discovered plants in the early season (mid to late May), as it dies back by September.
13) Procure funding for eradication projects, to be conducted by outfits such as the Exotic Plant Management Team.
14) Conduct additional studies based on the data generated from this survey, such as:
    - Does Norway maple facilitate the presence of garlic mustard?
    - Do invasive habitats alter behavior, nesting, or feeding in native birds versus native habitats?
    - Can floodplain maps model the distribution of invasive wetland species (purple loosestrife, glossy buckthorn, and *Phragmites*) in the park?
    - Does historic land use in the park correlate to the current abundance and distribution of the primary invasive species?

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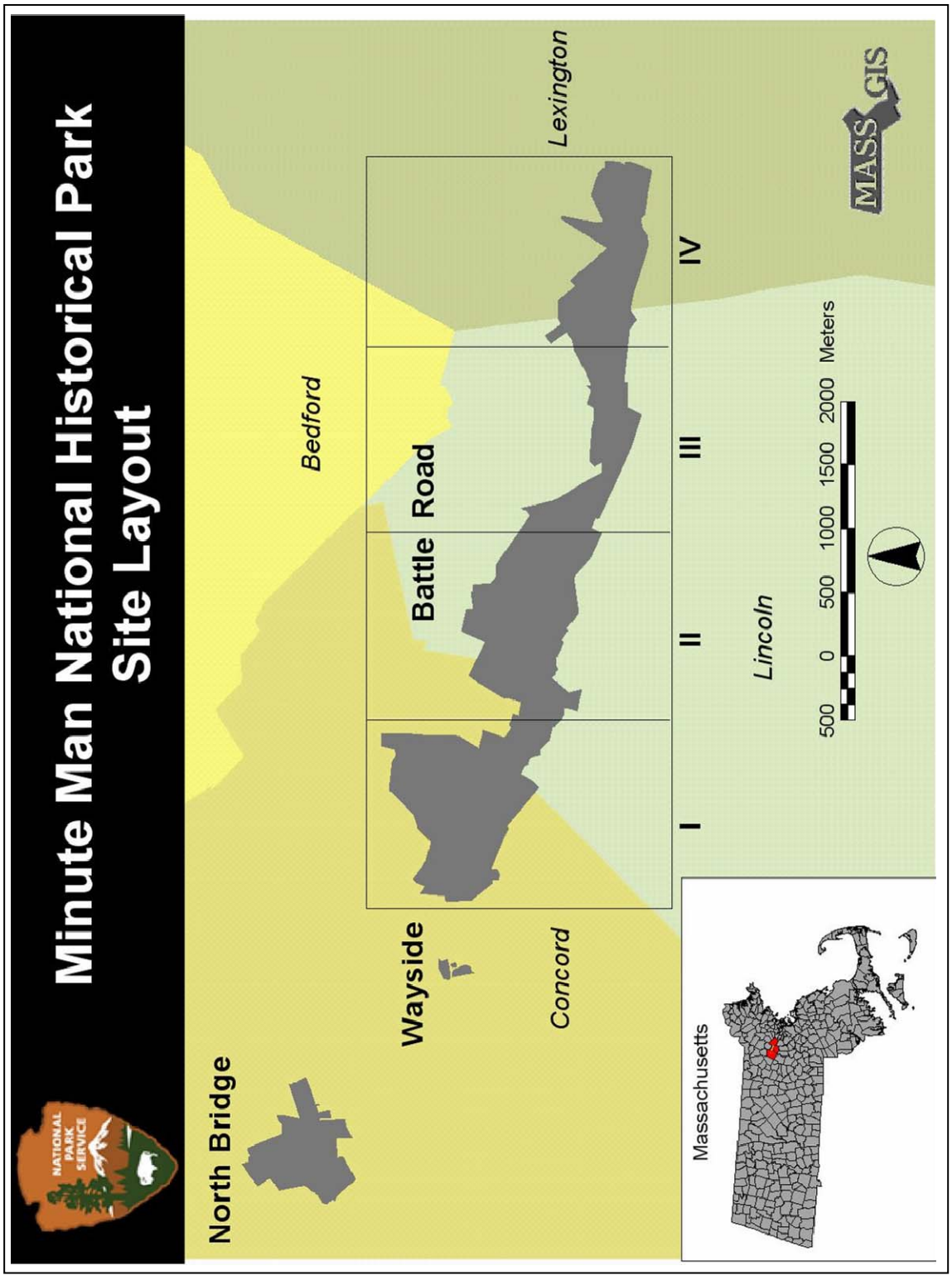
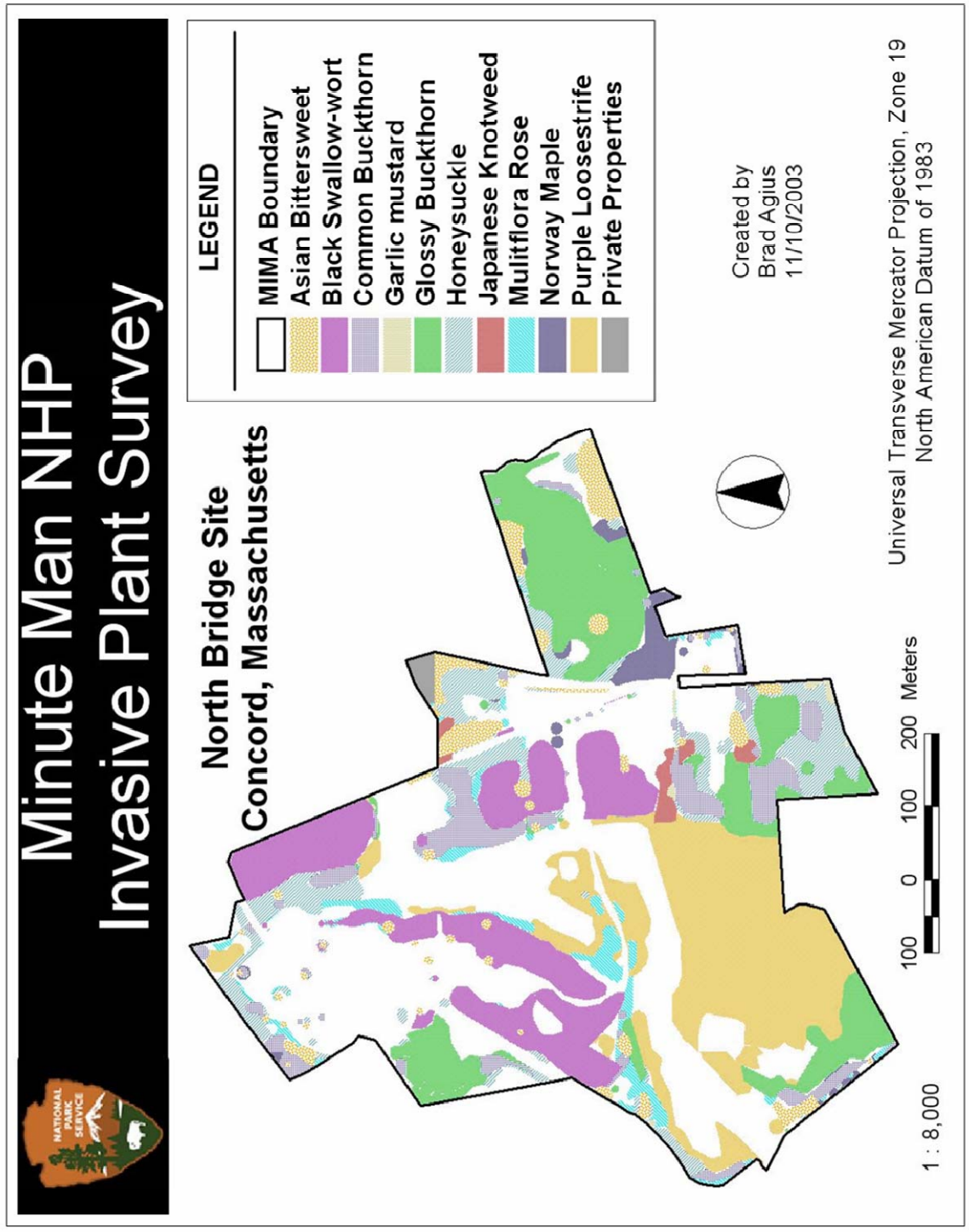
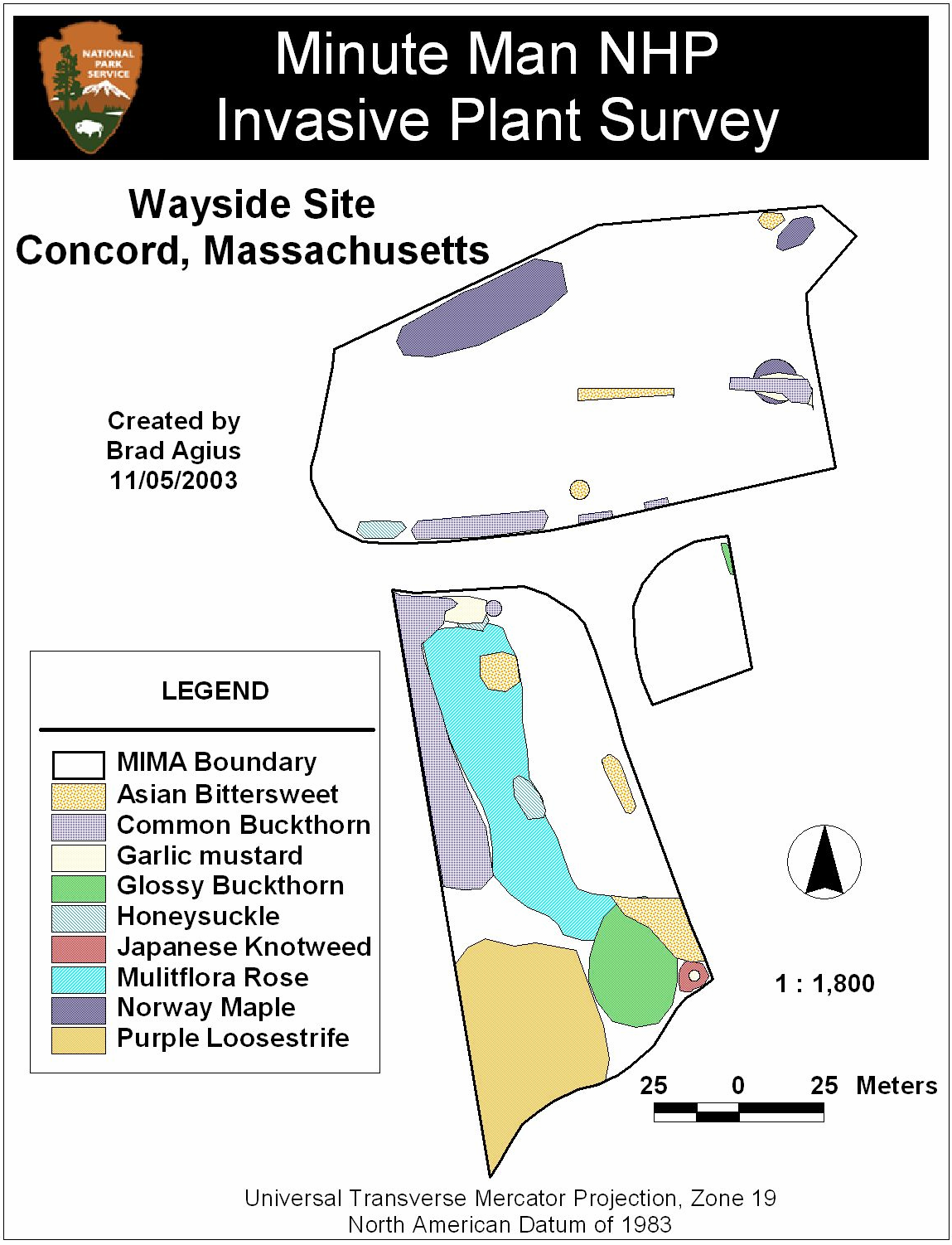
Appendix A. Minute Man National Historical Park: Site Layout Map. Shows all three Park Units (North Bridge, Wayside, and Battle Road) located in the towns of Concord, Lexington and Lincoln, Massachusetts. The Battle Road Unit is divided into four sections (I-IV) for Appendices D- G.



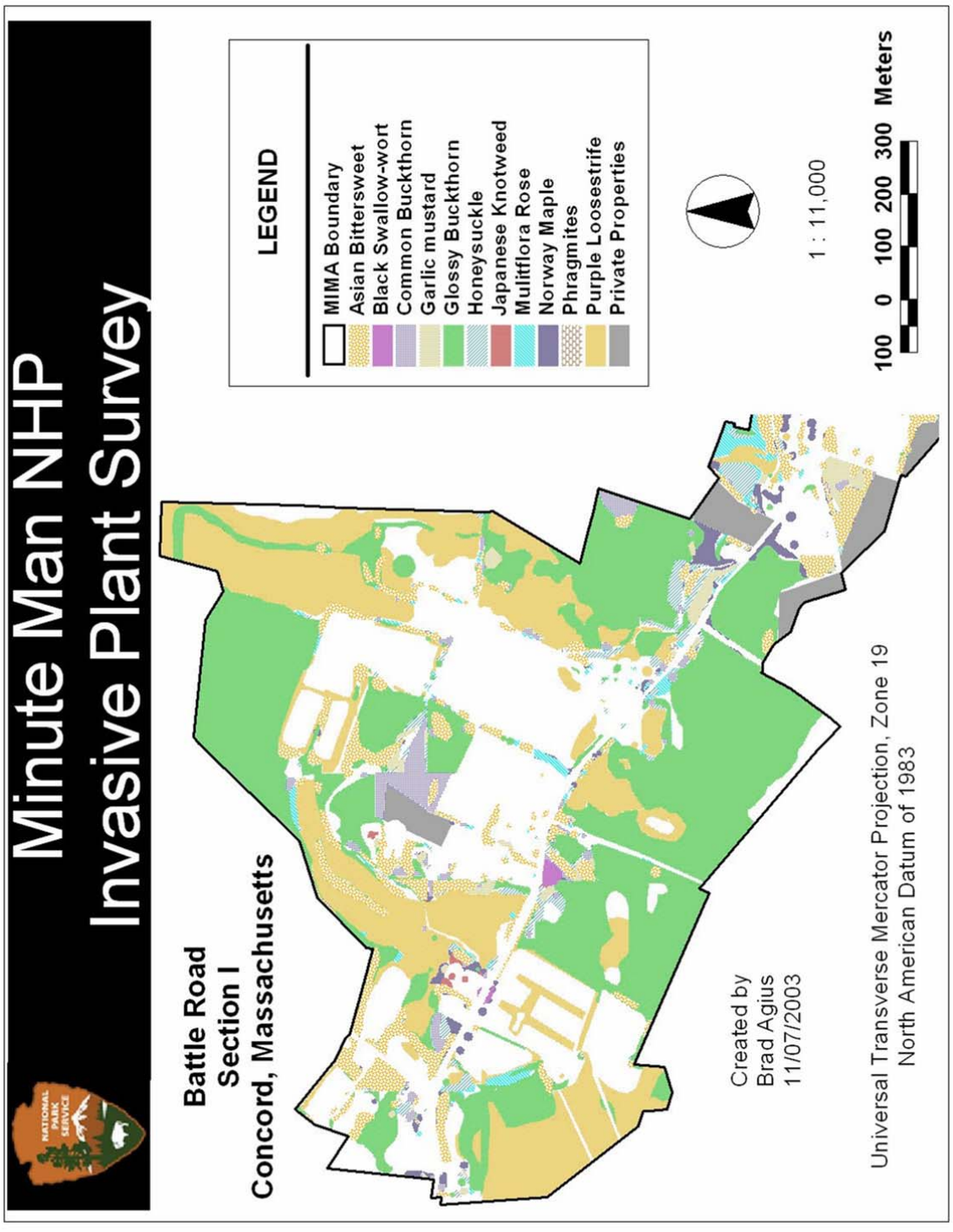
Appendix B. Minute Man National Historical Park Invasive Plant Survey: North Bridge Unit with all Primary Invasive Plant Species.



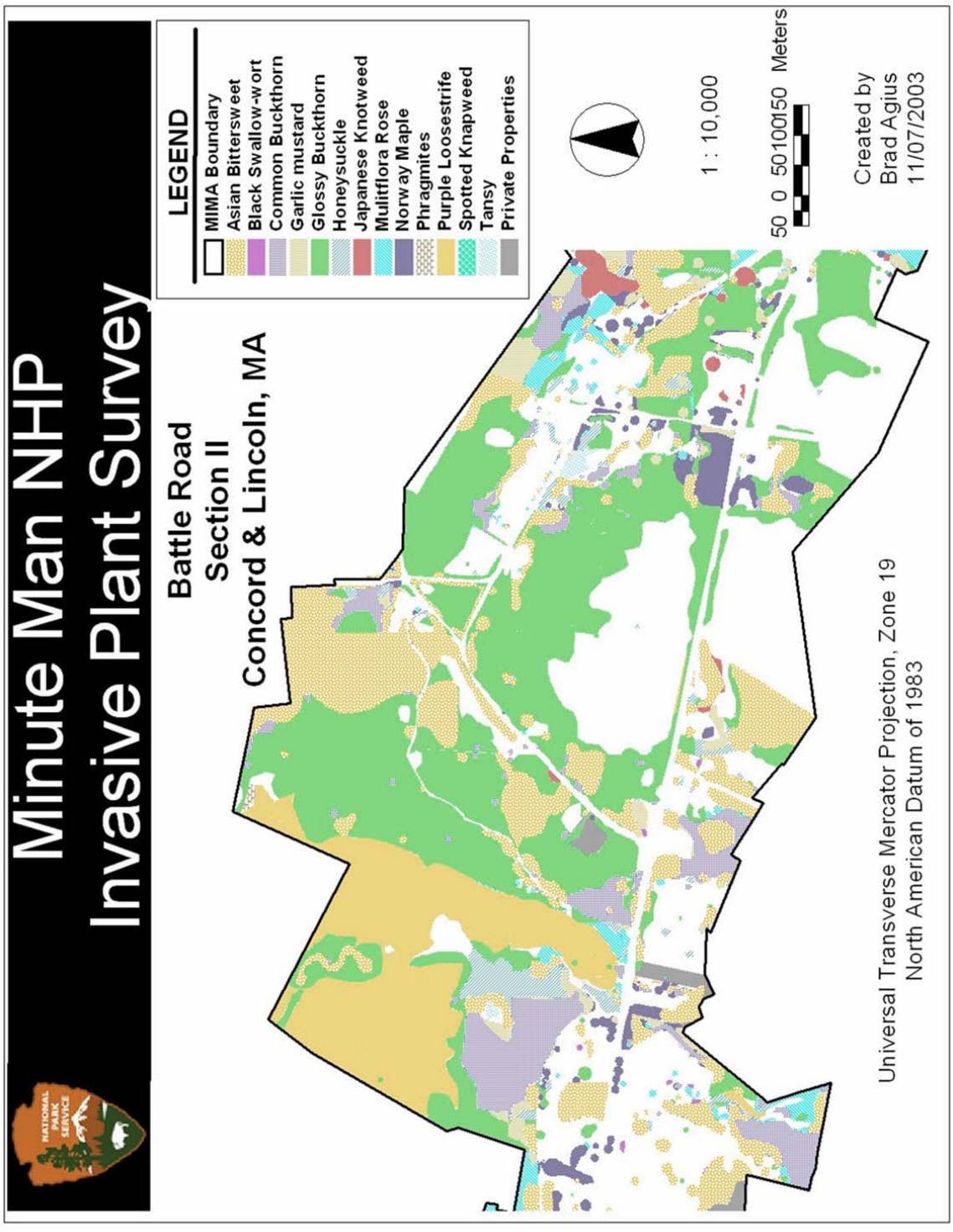
Appendix C. Minute Man National Historical Park Invasive Plant Survey: Wayside Unit with all Primary Invasive Plant Species.



Appendix D. Minute Man National Historical Park Invasive Plant Survey: Battle Road, Section I, with all Primary Invasive Plant Species.

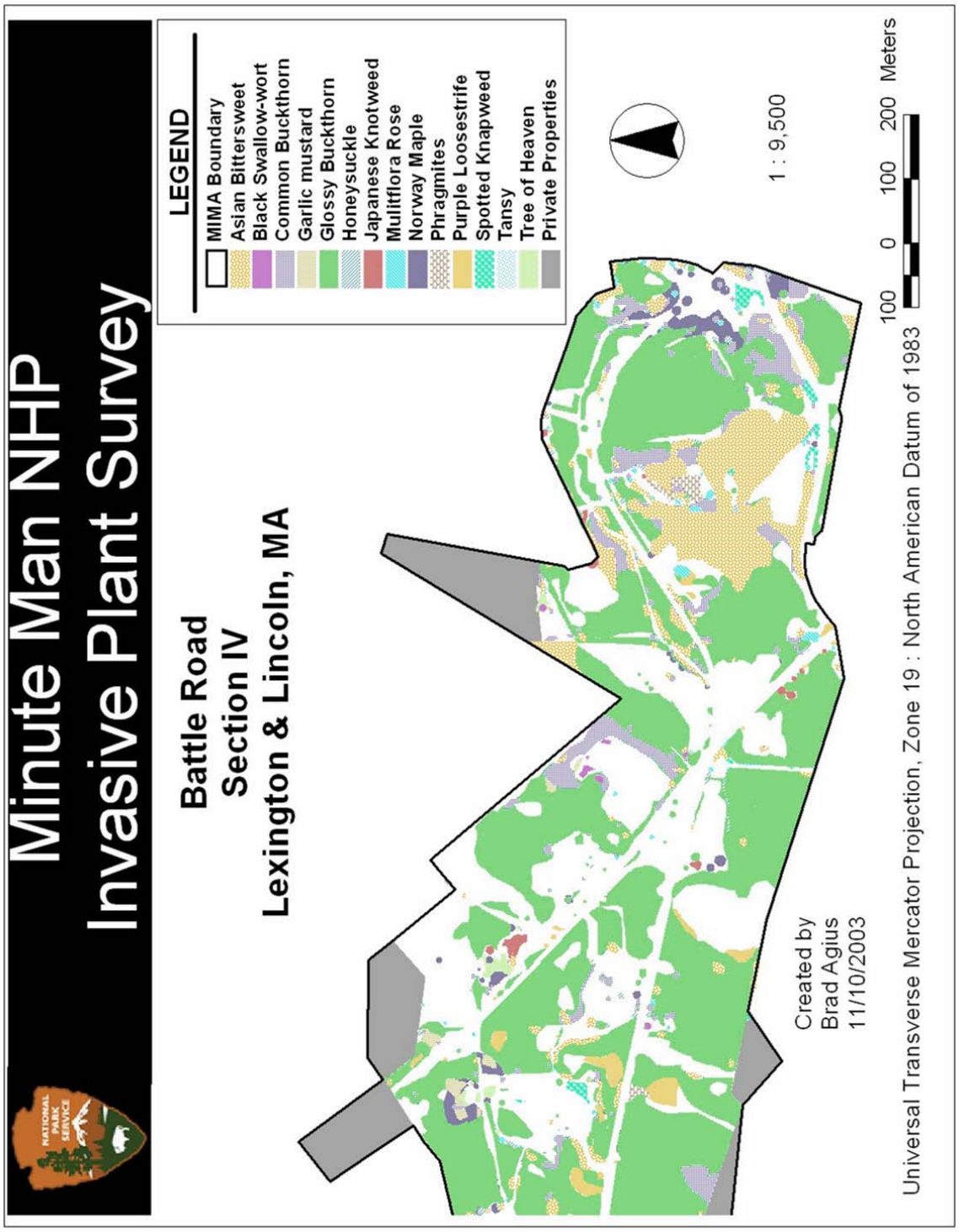


Appendix E. Minute Man National Historical Park Invasive Plant Survey: Battle Road, Section II, with all Primary Invasive Plant Species.

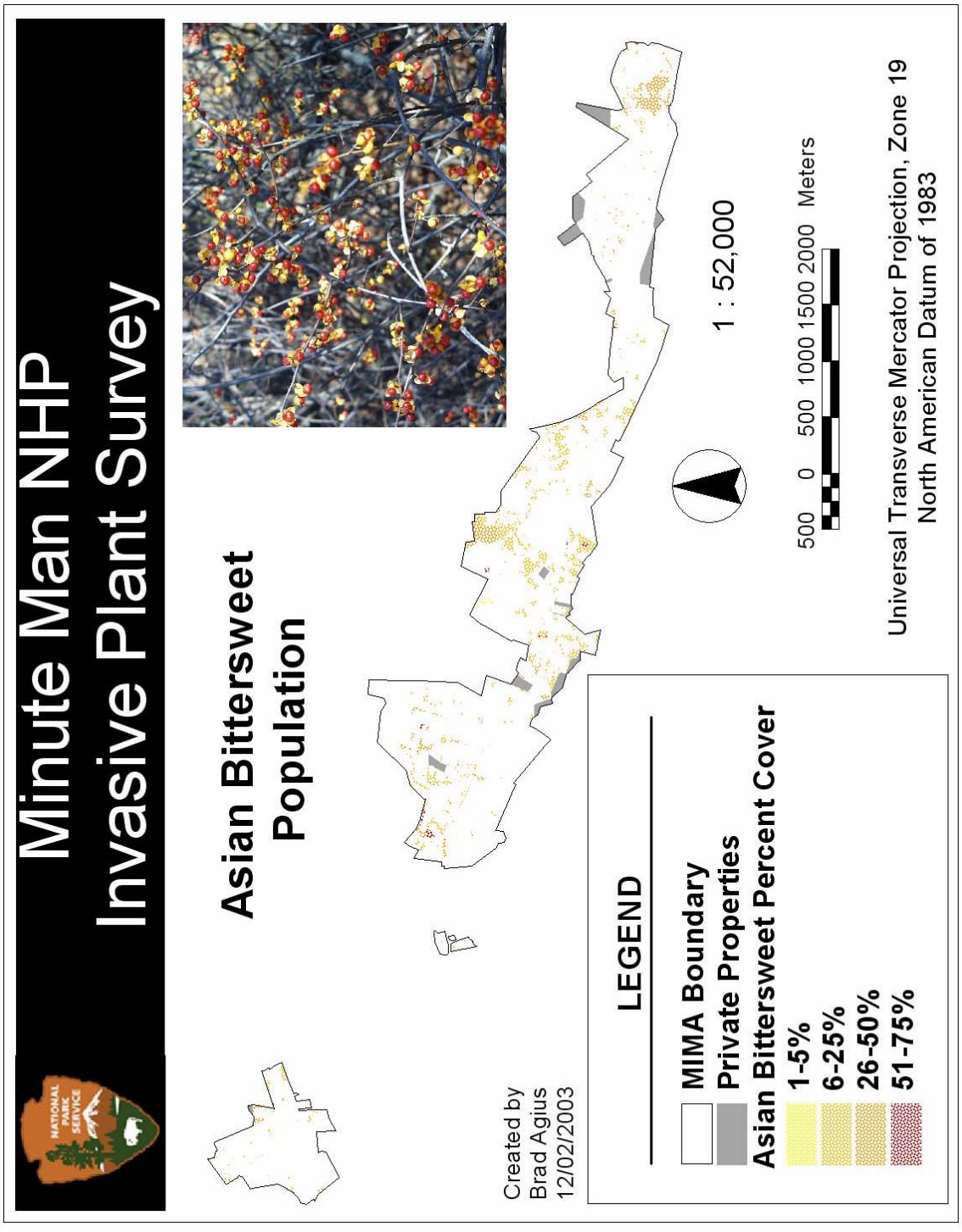


Appendix F. Minute Man National Historical Park Invasive Plant Survey: Battle Road, Section III, with all Primary Invasive Plant Species.

Appendix G. Minute Man National Historical Park Invasive Plant Survey: Battle Road, Section IV, with all Primary Invasive Plant Species.

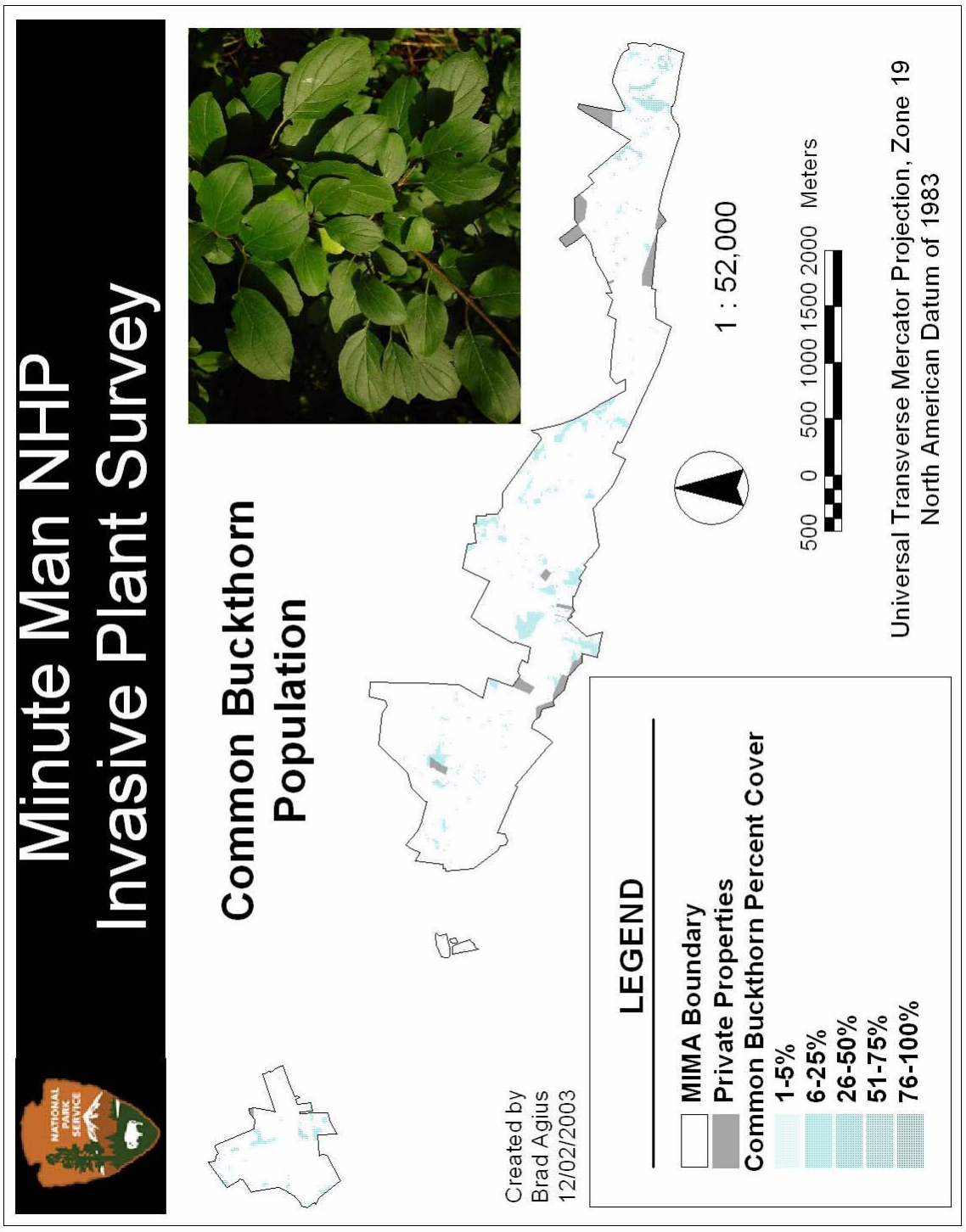


Appendix H. Minute Man National Historical Park Invasive Plant Survey: Asian Bittersweet Population Map.

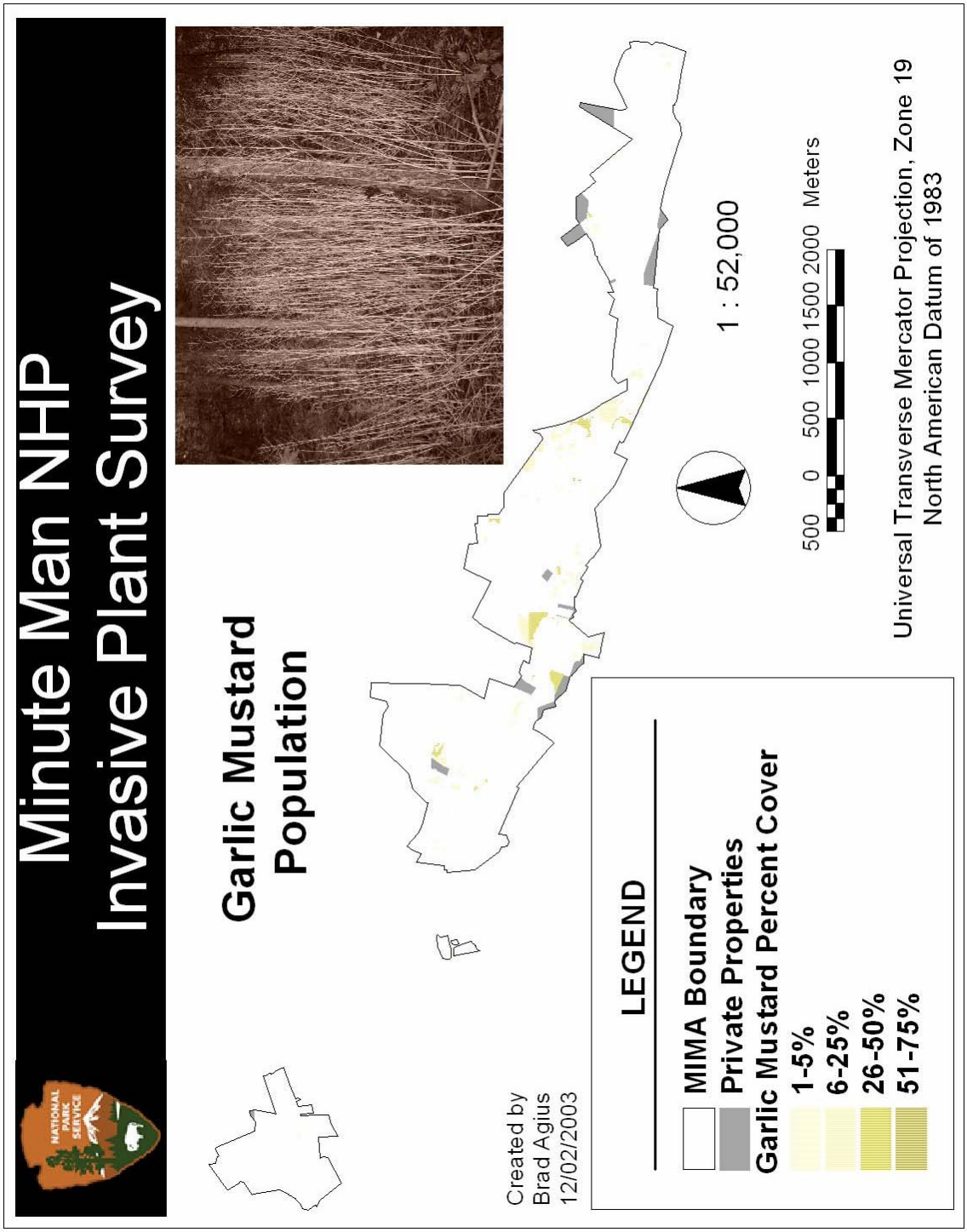


Appendix I. Minute Man National Historical Park Invasive Plant Survey: Black Swallow-wort Population Map.

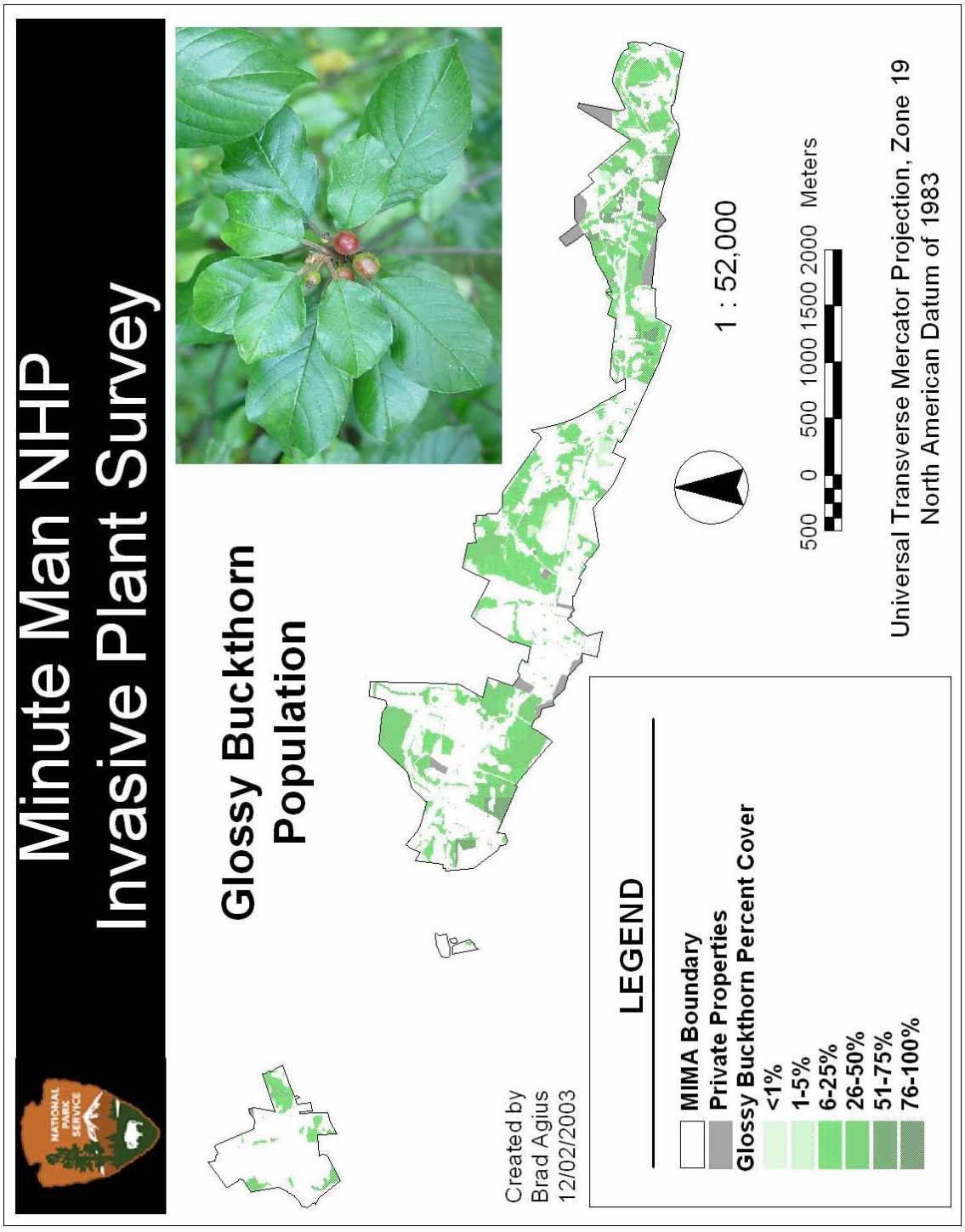
Appendix J. Minute Man National Historical Park Invasive Plant Survey: Common Buckthorn Population Map.



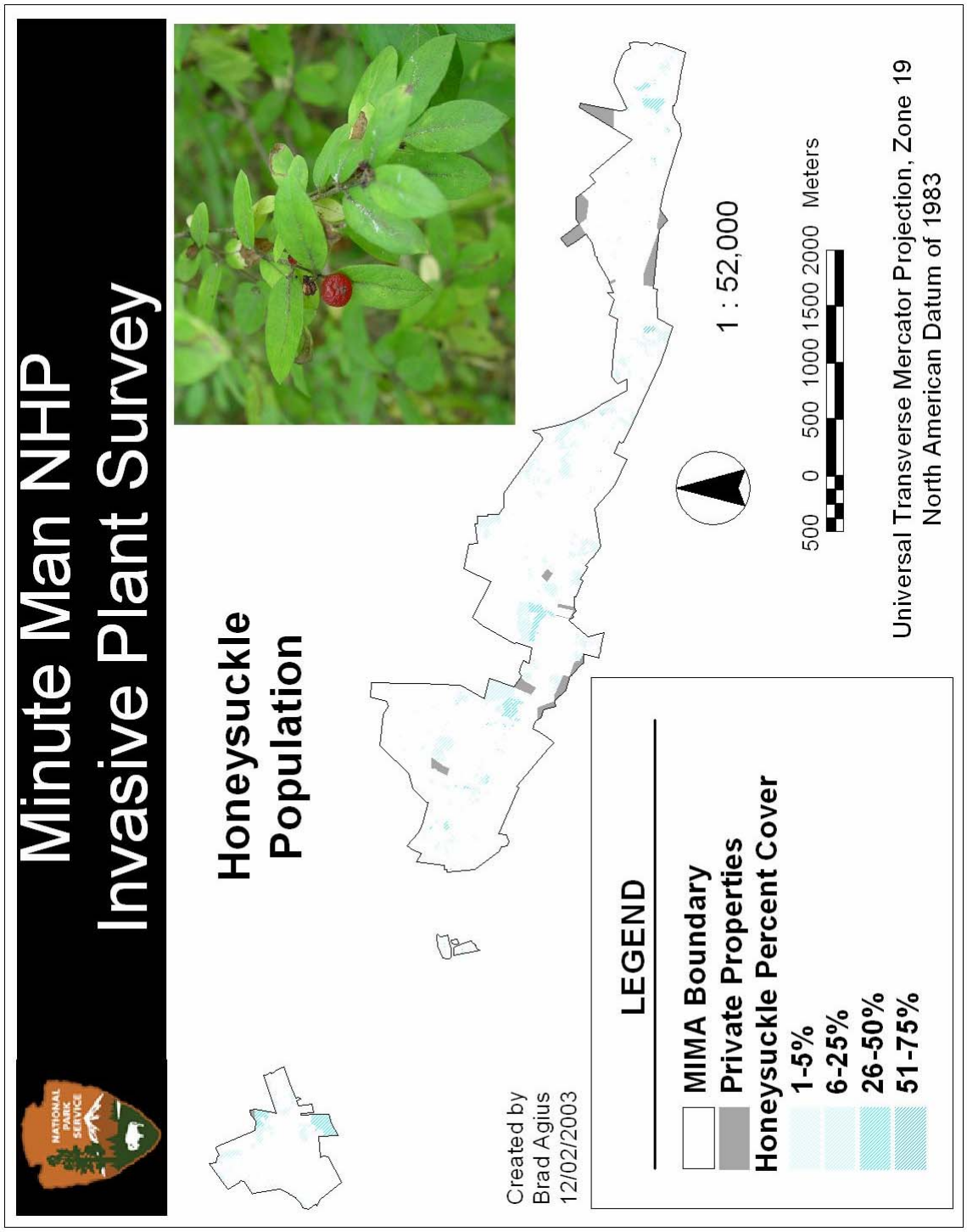
Appendix K. Minute Man National Historical Park Invasive Plant Survey: Garlic Mustard Population Map.



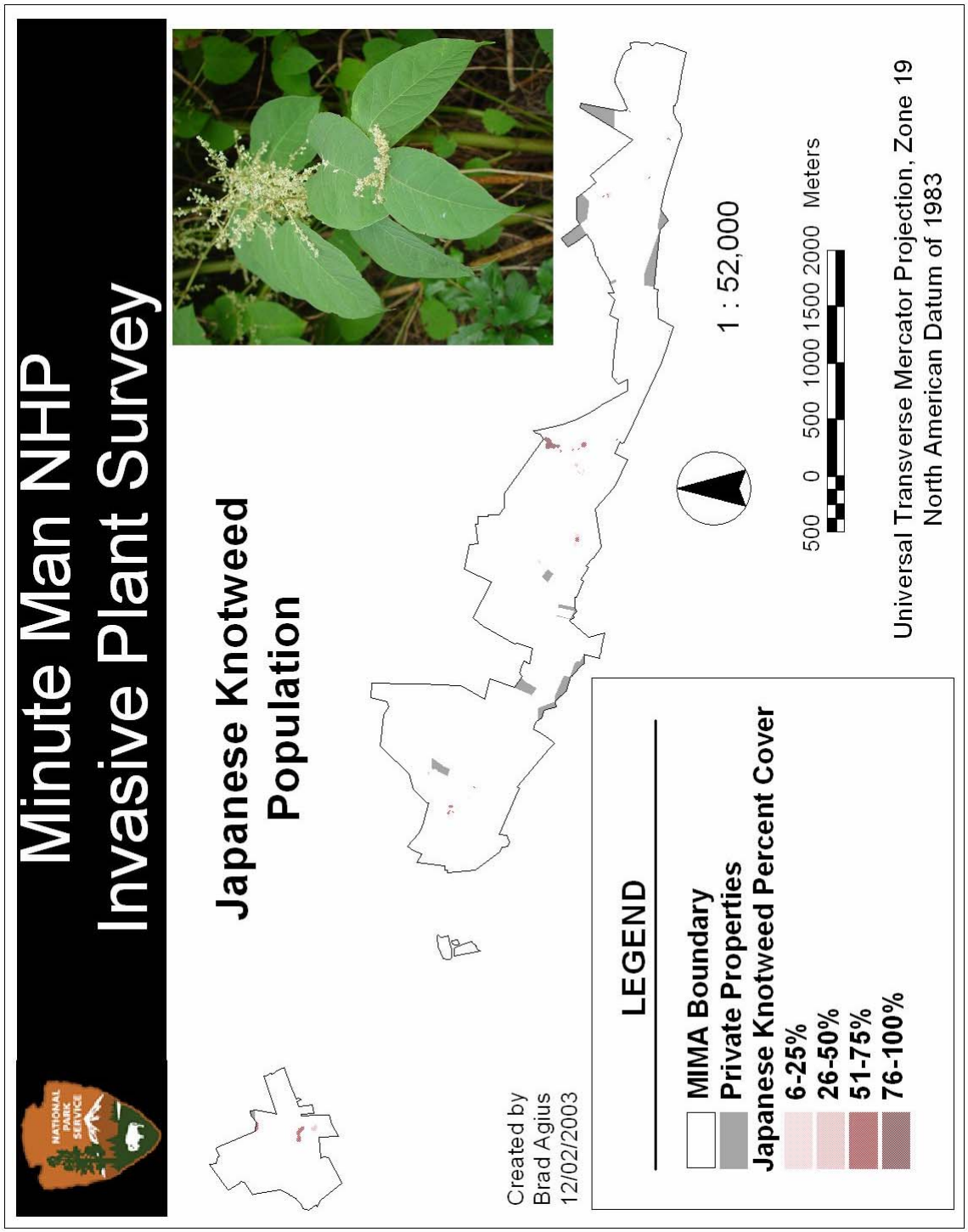
Appendix L. Minute Man National Historical Park Invasive Plant Survey: Glossy Buckthorn Population Map.



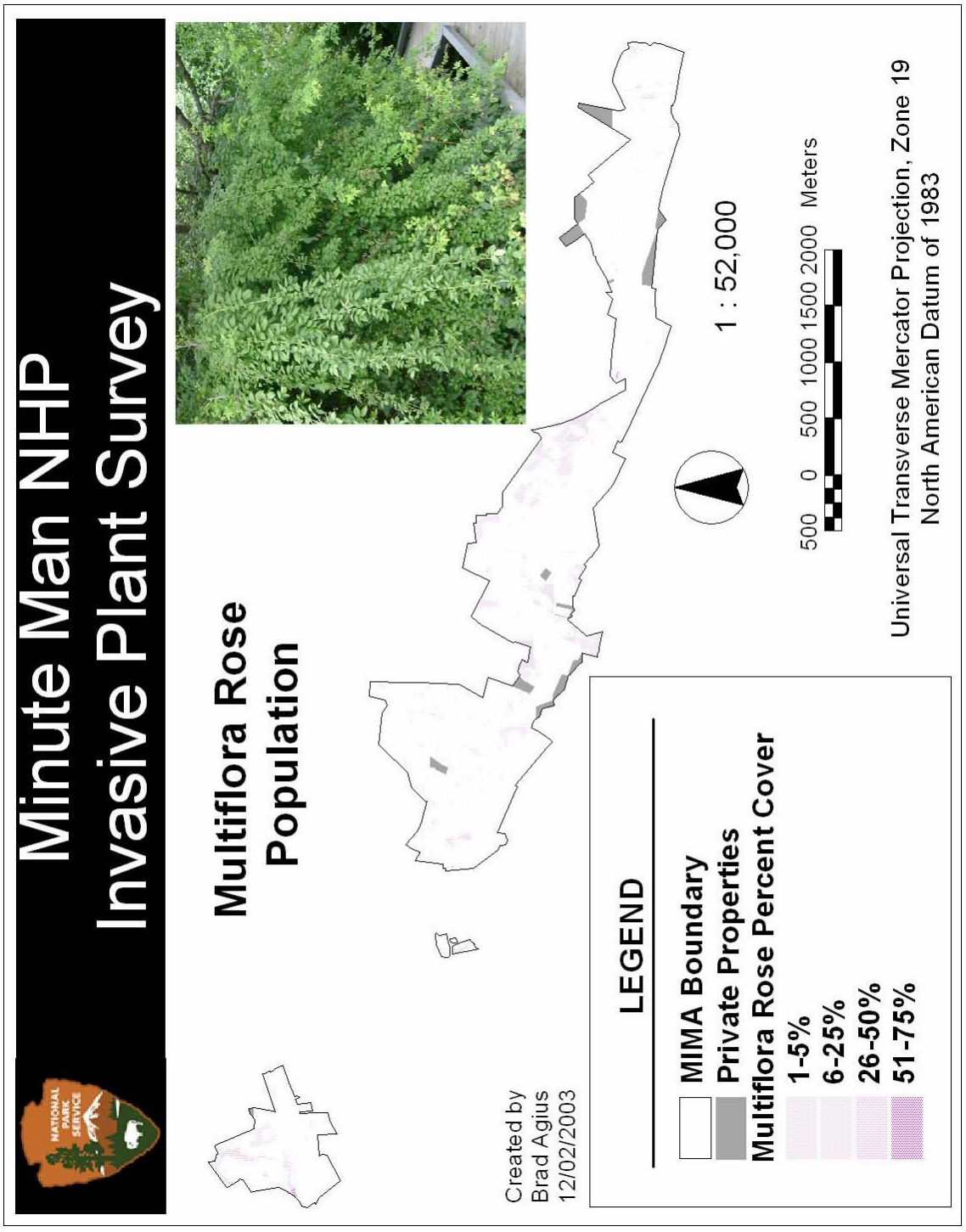
Appendix M. Minute Man National Historical Park Invasive Plant Survey: Honeysuckle Population Map.



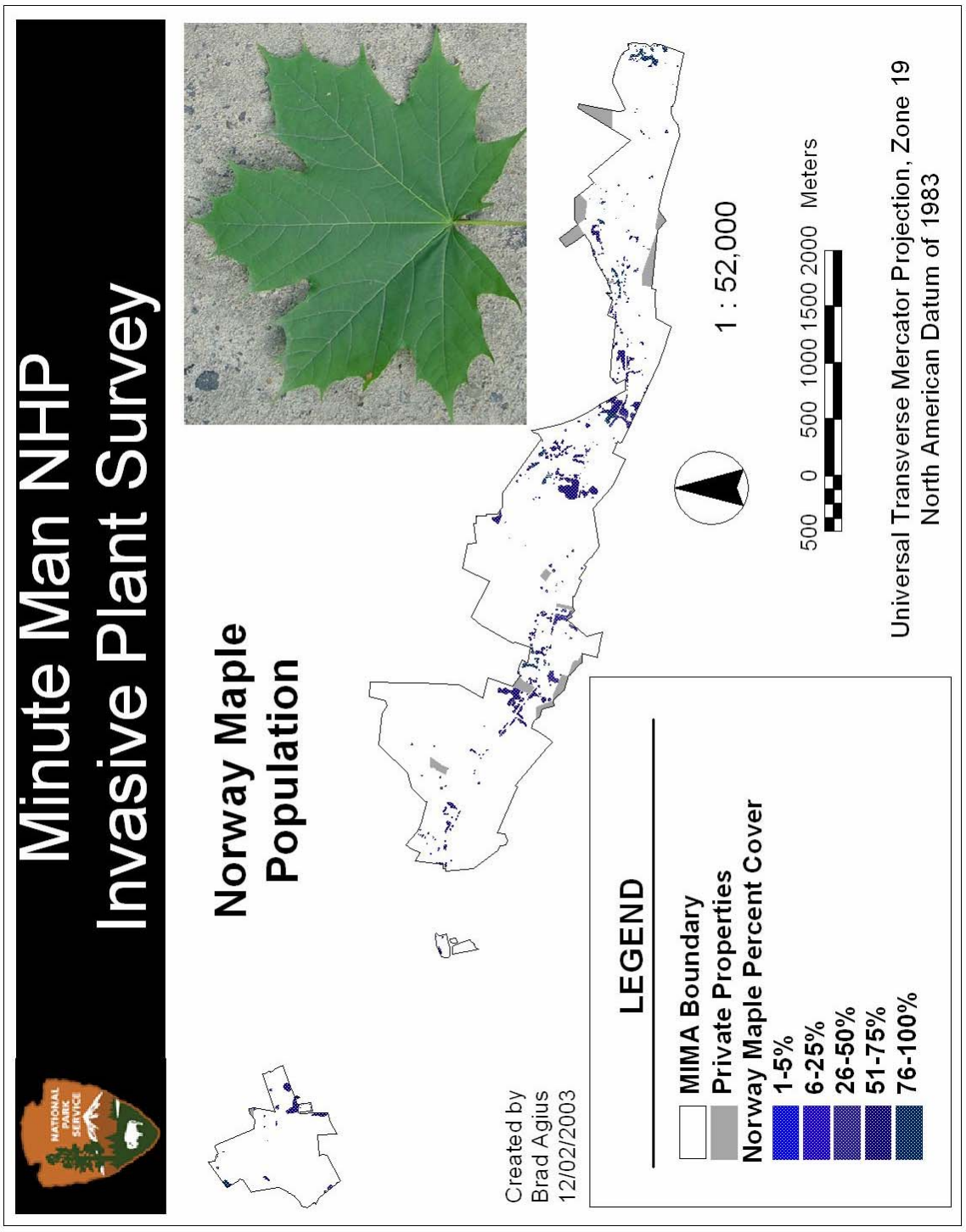
Appendix N. Minute Man National Historical Park Invasive Plant Survey: Japanese Knotweed Population Map.



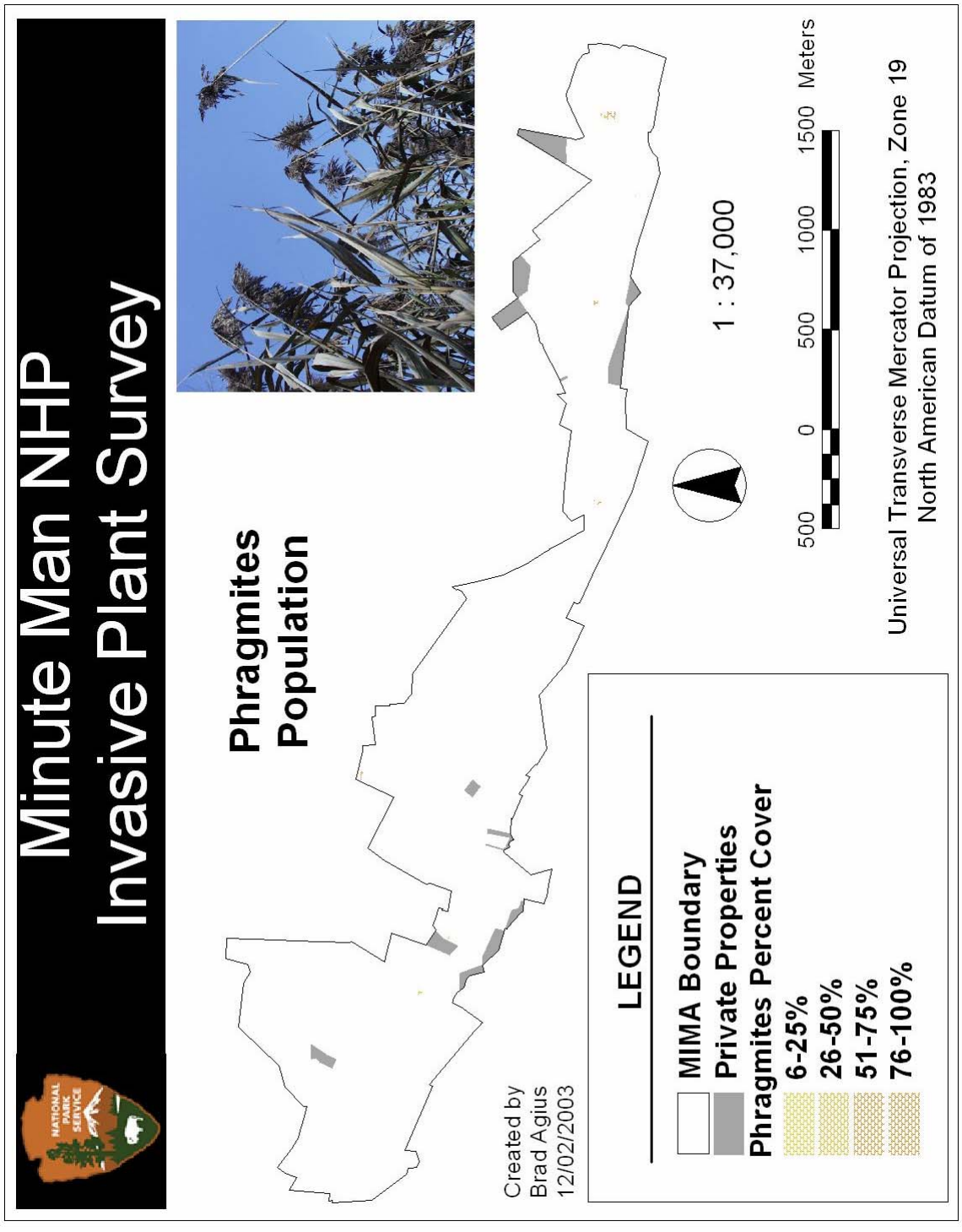
Appendix O. Minute Man National Historical Park Invasive Plant Survey: Multiflora Rose Population Map.



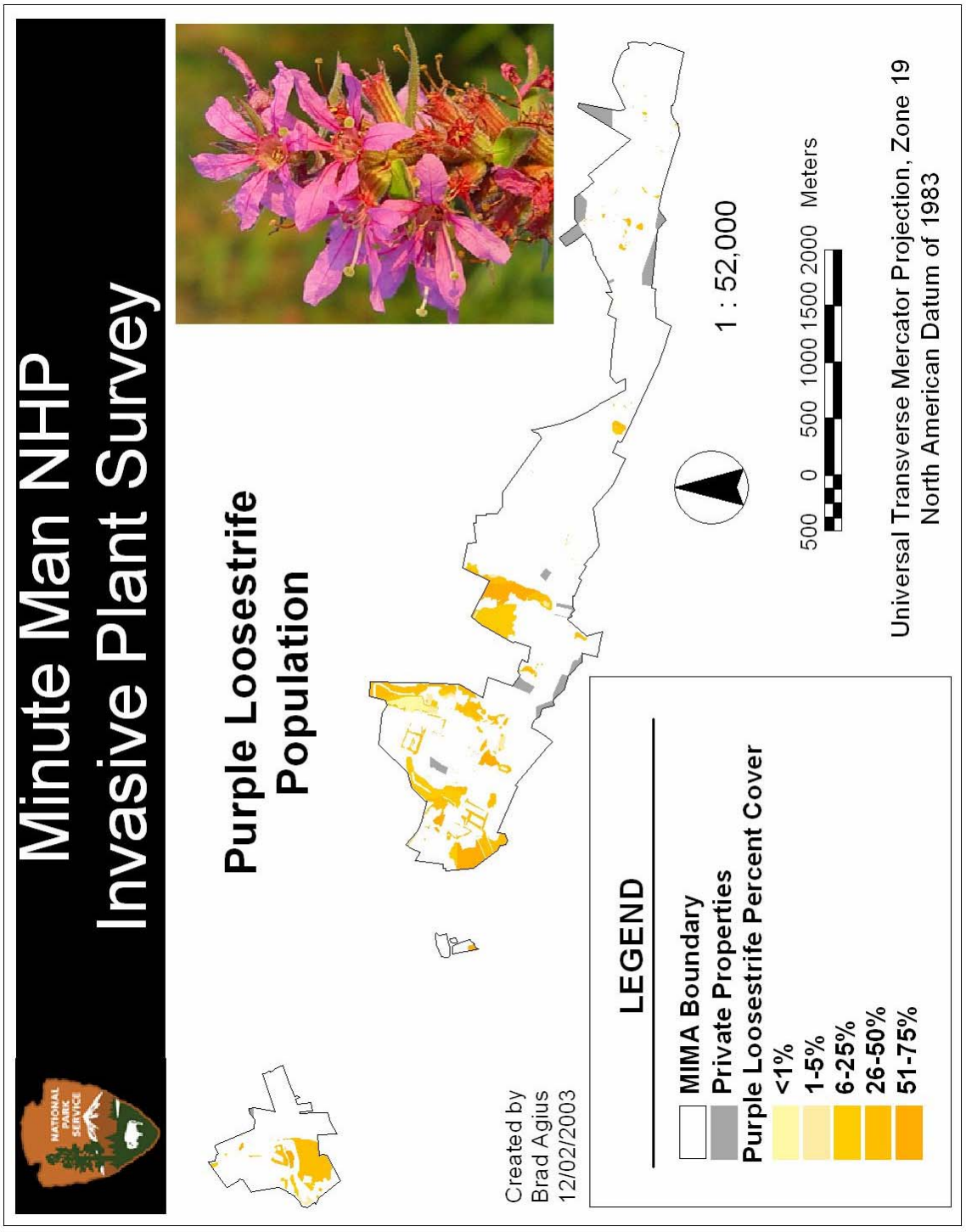
Appendix P. Minute Man National Historical Park Invasive Plant Survey: Norway Maple Population Map.



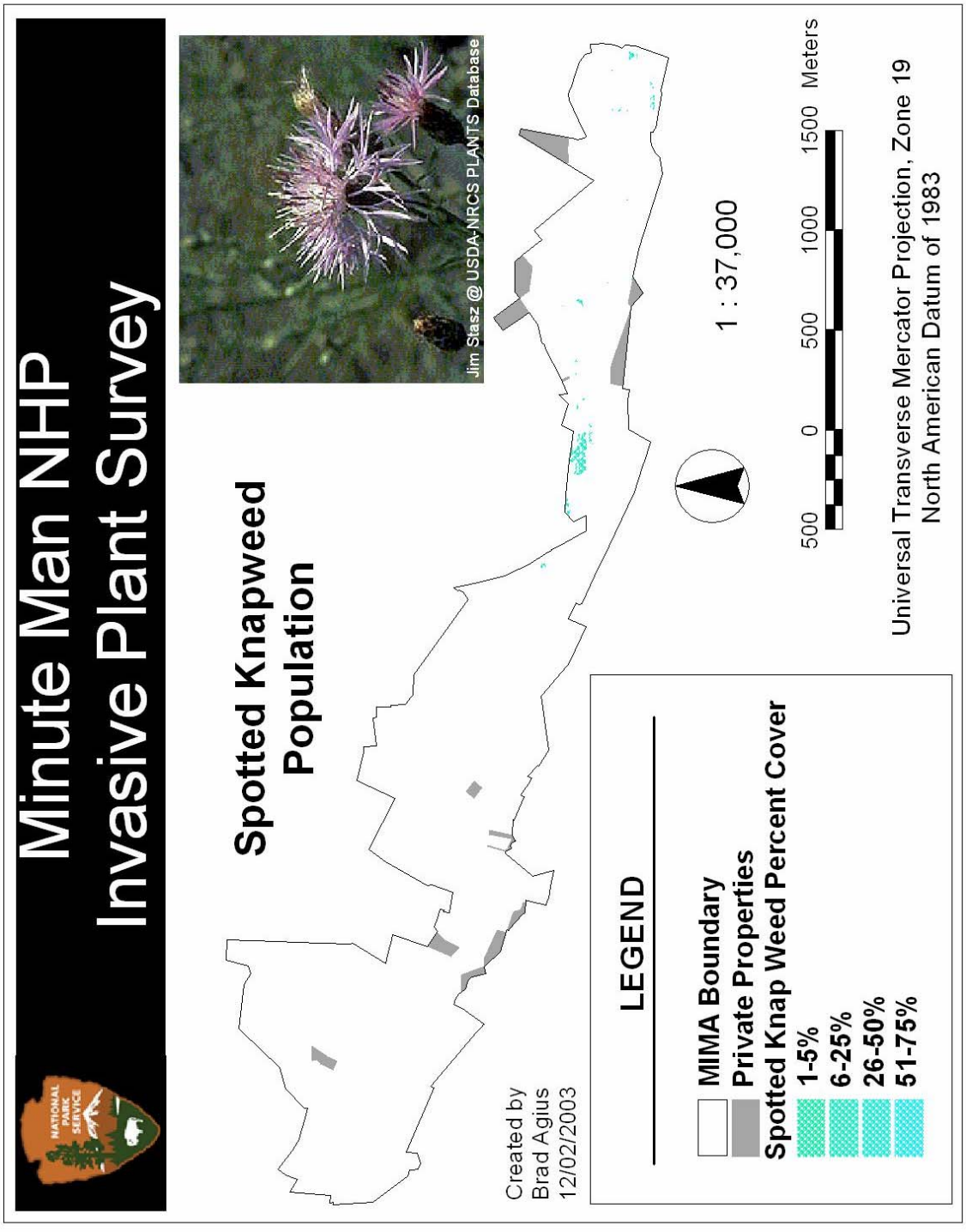
Appendix Q. Minute Man National Historical Park Invasive Plant Survey: Phragmites Population Map.



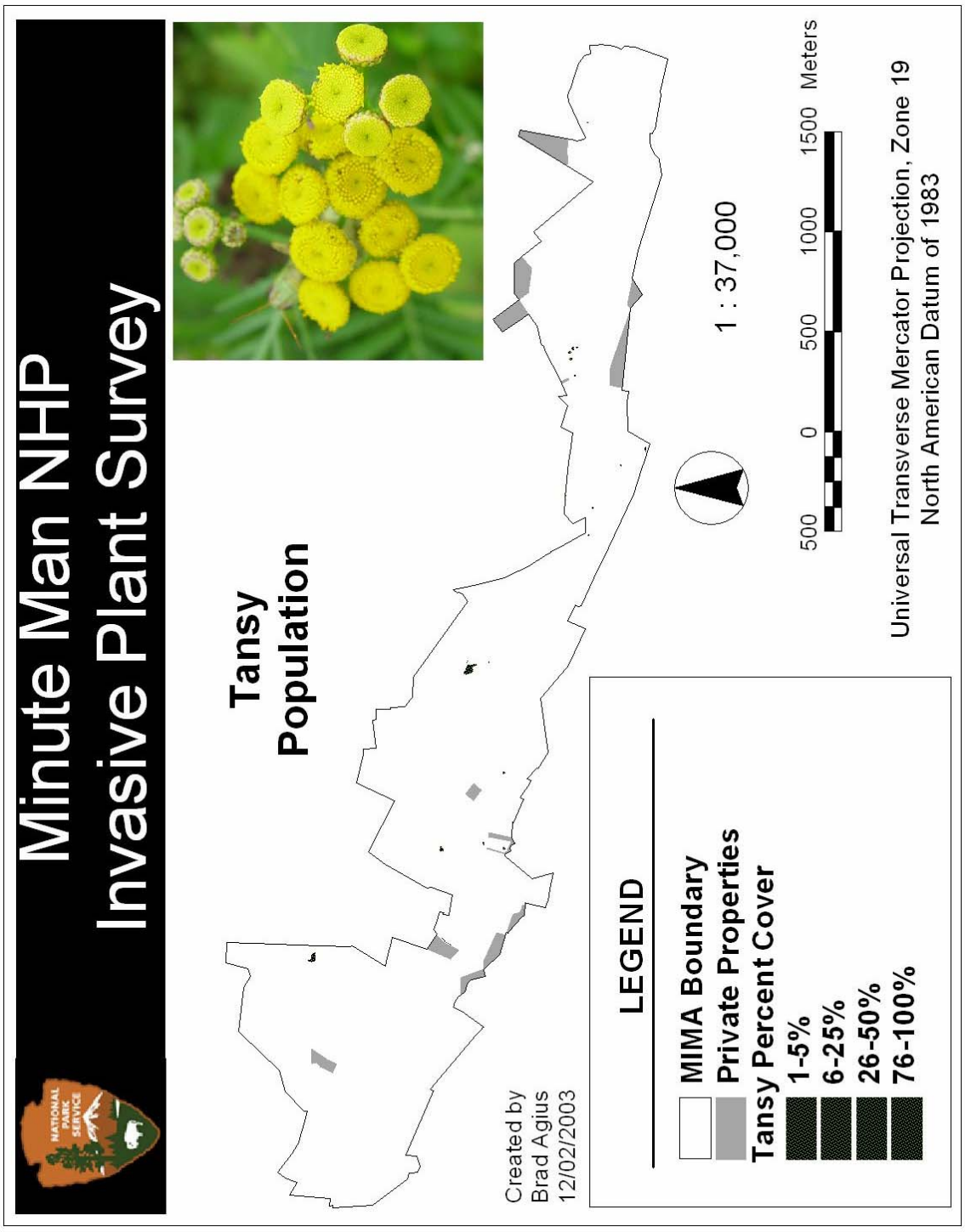
Appendix R. Minute Man National Historical Park Invasive Plant Survey: Purple Loosestrife Population Map.



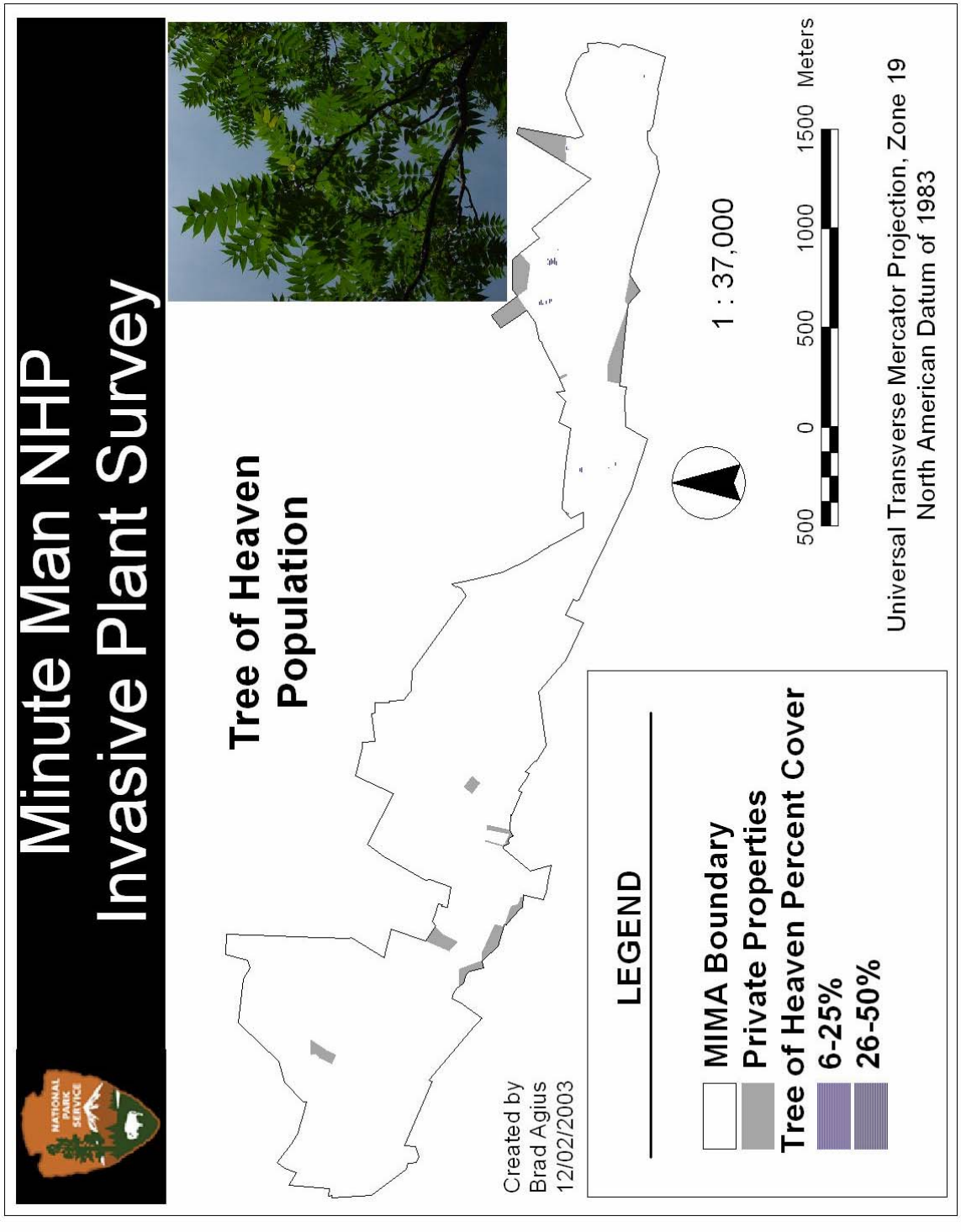
Appendix S. Minute Man National Historical Park Invasive Plant Survey: Spotted Knapweed Population Map.



Appendix T. Minute Man National Historical Park Invasive Plant Survey: Tansy Population Map.



Appendix U. Minute Man National Historical Park Invasive Plant Survey: Tree of Heaven Population Map.



As the nation's primary conservation agency, the Department of the Interior has responsibility for most of our nationally owned public land and natural resources. This includes fostering sound use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

NPS D-93 January 2005

National Park Service
U.S. Department of the Interior

Northeast Region
Inventory & Monitoring Program
Northeast Temperate Network
54 Elm Street
Woodstock, Vermont 05091

http://www1.nature.nps.gov/im/units/netn/index.cfm